USING PALYNOLOGY TO DETERMINE AGE AND PALEOENVIRONMENT OF PALEOCENE-EOCENE WILCOX GROUP SEDIMENTS IN BASTROP, TEXAS

A Dissertation

by

REGINA LEA DICKEY

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Chair of Committee,	Thomas Yancey
Committee Members,	Deborah Thomas
	Vaughn Bryant
	Anne Raymond
	Yeufeng Sun
Head of Department,	Michael Pope

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ABSTRACT

The Wilcox Group is an important group of sediments derived primarily from the Laramide orogeny in the western United States. It is important for paleoclimatological and paleoenvironmental studies, as it was deposited during the time of the Paleocene-Eocene Thermal Maximum (PETM), a time of rapid global increase in temperature. Wilcox Group sediments extend from central Texas into the deepwater Gulf of Mexico, but correlating these sediments is extremely difficult due to increased basinward faulting and sparse fossil content. The lack of macrofossils exists because sedimentation rates were high and large amounts of plant material were deposited, resulting in the destruction of calcareous fossils due to production of acids from decaying plant material. Thus, palynology remains the key to understanding these deposits.

Palynological sampling within shoaling-upward regressive deposits in the upper Calvert Bluff Fm at Red Bluff and overlying transgressive deposits of the Carrizo Fm, exposed beside the Colorado River near Bastrop, Texas, reveals a rich assemblage of well-preserved palynomorphs. This section contains an unconformity possibly equivalent to the sequence boundary between the Middle Wilcox and Upper Wilcox of the subsurface and previously thought to coincide with the Paleocene Eocene Thermal Maximum. Prior palynological work has placed the age of the upper Calvert Bluff near Bastrop in the late Paleocene, but this study has shown that these sediments are probably Eocene, with the P/E boundary subsurface to the outcrops. Therefore, the palynomorphs

present here would potentially record a response in flora during and after the PETM. My research utilizes palynology to refine the age of the sediments and produce a detailed palynological framework around the P/E boundary for this particular Wilcox interval, lending to a better understanding of the effects of the PETM along the western U.S. Gulf Coast.

DEDICATION

To Dale, who makes everything possible.

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All other work conducted for the dissertation was completed by the student independently.

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NOMENCLATURE

P/E	Paleocene/Eocene
PETM	Paleocene Eocene Thermal Maximum
RHTS	Red Hot Truck Stop

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CHAPTER I

INTRODUCTION

Sedimentary deposits of the Wilcox Group are the product of a major flood of sediments carried to the Gulf of Mexico coastal plains during the early part of the Paleogene (Fisher and McGowen, 1969; Winker, 1982). Wilcox sediments in the Texas sector of the Gulf of Mexico province are derived from the central Rocky Mountains that were formed by Laramide uplift (Galloway et al., 2011; Wahl et al., 2016). Erosion of the Laramide Rocky Mountains during the Late Paleocene produced large amounts of sediment that was carried by rivers to the Gulf of Mexico coastal plains and continental shelf, with the center of sediment accumulation located in the northwest corner of the Gulf. Deposition of these sediments produced a great depositional complex that prograded the shelf margin in that portion of the Gulf and fed a large volume of sediments into the deeps of the northern part of the Gulf of Mexico (Zarra, 2007). This set of deposits is a major reservoir of hydrocarbons and also contains large lignite deposits in the outcrop belt of the northwestern and north-central Gulf coastal plains (Kaiser, 1978). Fisher and McGowen (1967) summarized patterns of Wilcox sediment deposition in Texas, based on data compiled from numerous boreholes and outcrop belt exposures. This overview of major depositional systems and depositional geometry provides the framework utilized by many reports on the pre-Carrizo Wilcox Group. However, documentation of extensive marine deposits in the upper part of the Calvert Bluff Formation reveals a resetting of depositional environments in the upper part of the

Wilcox studied by Fisher and McGowen (1967), an interval deposited during the Sabinetown transgression (Yancey et al, 2012).

Sediments of the Wilcox Group exposed in the outcrop belt were deposited during the Late Paleocene and Early Eocene, beginning in the late Selandian and continuing until the basal Eocene (Crabaugh and Elsik, 2000; Elsik and Crabaugh, 2001). The overlying Carrizo Formation, included within the Wilcox Group in most industry literature, is of Early Eocene age (Crabaugh and Elsik, 2000; Rosen, 2007; Brown and Loucks, 2009; Yancey et al., 2012). Historically, outcropping strata of the Wilcox Group in Texas have been dated as being Eocene in age (Fisher, 1961; Fisher and McGowen, 1967), with the Paleocene-Eocene boundary placed at the base of the Wilcox Group and that age determination is presented in early reports on the Wilcox. The lack of marine fossils in Wilcox Group outcrops provided no basis for age assignment, a problem that was overcome only when palynomorphs were extracted and used for age determination (Fairchild and Elsik, 1969; Nichols and Traverse, 1971; Elsik, 1978). This work indicated that the Paleocene-Eocene boundary lay in the upper Calvert Bluff Formation at a horizon that placed most of the Texas outcrops of Wilcox Group in the Paleocene.

The Wilcox Group, therefore, spans the Paleocene-Eocene boundary and should contain a record of the unusual climates of that time, during the time interval termed the Late Paleocene Thermal Maximum or Paleocene-Eocene Thermal Maximum (PETM) (Zachos et al. 1994). The PETM was a time of rapid and intense global warming, possibly caused by an unusually large release of methane from hydrates in the ocean floor (Zachos et al., 2008, Lunt et al., 2010, Thomas, et al., 2002), released over a 10,000 year

time interval (Dickens, 2003). A global warming event occurred, with temperatures 5-7 degrees C higher than preceding or subsequent times (Zachos et al., 1994). During the warming event, the tropics probably warmed to 40° C (Aze et al., 2014). The warming in middle and high latitudes resulted in northward migration of warm climate plants and animals into higher latitudes than present during the preceding Paleocene time. Instead of experiencing mass extinctions, plants and animals made large-scale migrations across high latitude land corridors connecting Eurasia and North America into new areas.

Given the distinctive nature of this short-term global event, it should be possible to identify the PETM event in the fossil record within Wilcox Group strata. Typically, the PETM is identified by key indicators, including the negative carbon isotope excursion of Zachos et al. (2008) and a flood zonal occurrence of *Platycarya* pollen and/or *Apectodinium* dinoflagellates, the "*Apectodinium* flood" of Sluijs et al. (2007). All of these indicators should be present in nearshore Wilcox strata if sediment deposition occurred during the PETM in this area. Accurate dating of Wilcox Group sediments will provide a means of determining sea level variation and a means of locating sediments deposited during the PETM.

This report presents a detailed record of pollen and spores for the upper part of the Calvert Bluff Formation in an area where closely spaced sampling is possible. The biota of the Wilcox Group in the northwestern part of the Gulf of Mexico is poorly documented, despite the high level of interest in the interval. The section is thick but fossil content is sparse, except for the pollen and spores of terrestrial land plants and cysts of freshwater algae and marine dinoflagellates. Organic acids produced by the decay of

plant tissue are responsible for the diagenetic loss of nearly all carbonate and phosphatic remains. In contrast, organic walled microfossils are abundant and well preserved throughout the Wilcox Group. Therefore, palynology provides the best means of determining age relations and documenting the record of environmental change for these deposits.

This study is focused on upper Wilcox Group sediments beneath and including the boundary with the Carrizo Formation located in Bastrop County, Texas (Figure 1), where outcrops of the upper Calvert Bluff and Carrizo Formations are well exposed along bluffs of the Colorado River (30° 04' 24" N.; 97° 16' 48" W). These strata have been examined during many geological field trips and are documented in several publications (Harris, 1962; Crabaugh and Elsik, 2000; Jardine and Harrington, 2009; Yancey et al., 2010; Yancey et al., 2012). A nearby set of exposures of upper Calvert Bluff and Carrizo formations on Sandy Creek is described by Atlee et al. (1968).

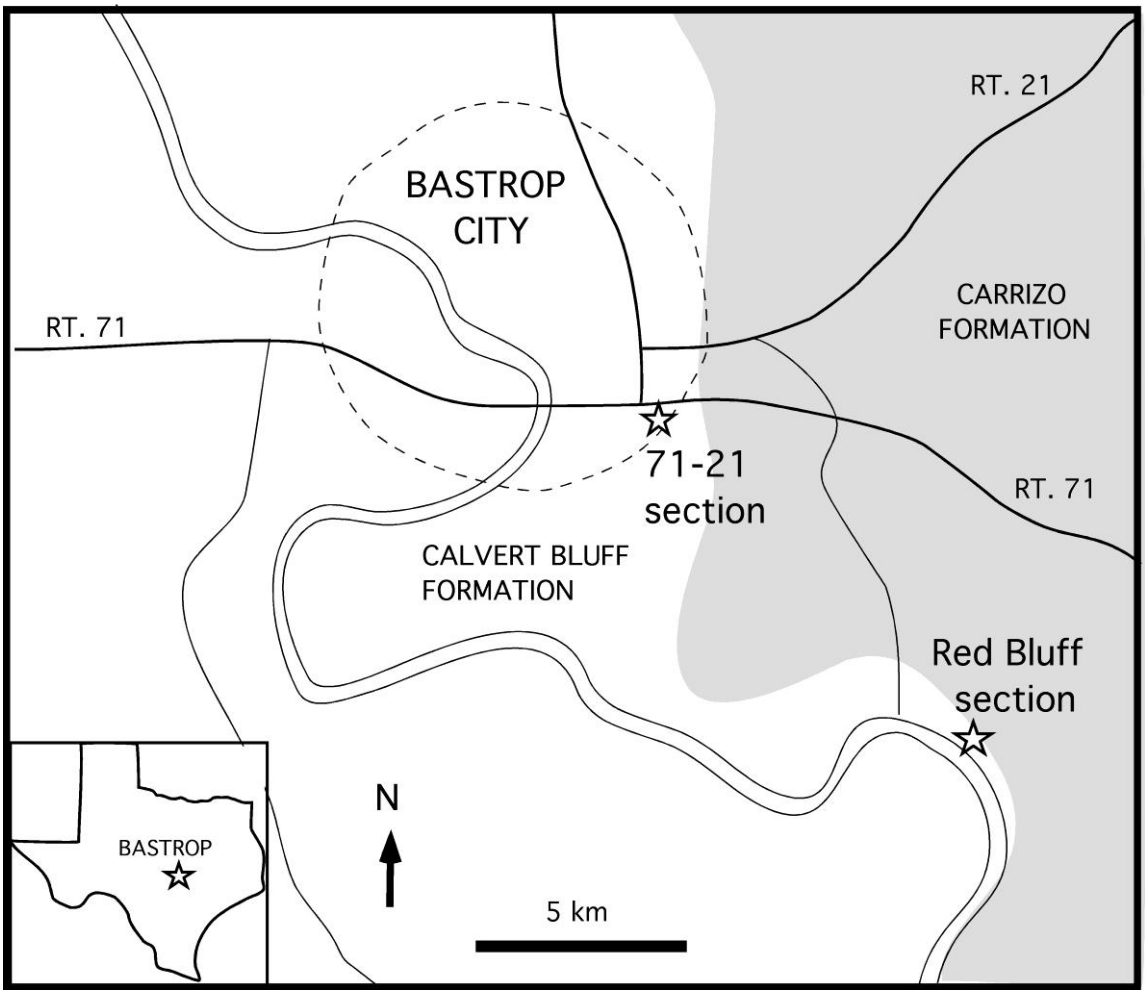


Figure 1. Location map of the study area at Bastrop city, Bastrop County, Texas

CHAPTER II

GEOLOGIC BACKGROUND

The Wilcox Group is a thick interval of clastic sandstones and mudstones deposited during the Paleocene and Eocene (Figure 2). Major depositional systems of Wilcox Group sediments are characterized as consisting of fluvial plains and coastal deltaic complexes (Fisher and McGowen, 1969). Both of these systems are mapped as outcropping within Bastrop County. The Mt. Pleasant fluvial system occurs updip and consists primarily of fluvial channel deposits and overbank sediments. The downdip Rockdale delta system contains up to 1525 meters (5000 ft.) of mudstone and sandstones in a river distributary-marsh-swamp facies that has been compared to the modern day Mississippi delta system in both size and scope (Fisher and McGowen, 1969). This reconstruction may be appropriate for the Simsboro Formation of the Wilcox Group, but is inappropriate for most of the Calvert Bluff Formation. The upper Calvert Bluff contains marine deposits of the Sabinetown transgression (Yancey et al., 2012), one of the major transgressions of the northern Gulf of Mexico region.

The Wilcox Group of Fisher and McGowen (1969) and the limits of the Wilcox as mapped on surface geology maps in Texas is the interval of deposits above the fossiliferous marine deposits of the Midway Group and below the sandstones of the Carrizo Formation. This interval is known either as the Lower Wilcox or the Lower and Middle Wilcox in subsurface literature (Fisher and McGowen, 1967, Winker, 1982; Galloway et al., 2000; Zarra, 2007), which groups the Carrizo Formation and age-

equivalents with the older Wilcox deposits as parts of the same great flood of sediment delivered to the Gulf of Mexico. The termination of this great clastic wedge is associated with the Reklaw marine transgression that signaled change to a different style of sediment deposition contained in the Claiborne Group (Winker, 1982).

The upper part of Fisher and McGowen's Wilcox interval corresponds to the Calvert Bluff Formation in the outcrop belt and is separated as the Middle Wilcox by Xue and Galloway (1995). This includes strata between the Big Shale and the Yoakum Shale of the subsurface. The upper part of the Calvert Bluff Formation contains some deposits with normal marine fossils and is sometimes separated from the Calvert Bluff Formation as the Sabinetown Formation (Harris, 1962; Jones, 1986; Crabaugh and Elsik, 2000). This use of the name is primarily a subsurface convention, because the Sabinetown Formation is not utilized in geologic maps of outcrop exposures of Wilcox strata by the Geologic Atlas of Texas (Barnes, 1974). In the Bastrop area, the Carrizo Formation directly overlies the Calvert Bluff Formation. Although Jones (1986) used borehole log response to identify a Sabinetown interval in the shallow subsurface, the lithology of this interval is not distinct enough to be mapped in outcrop.

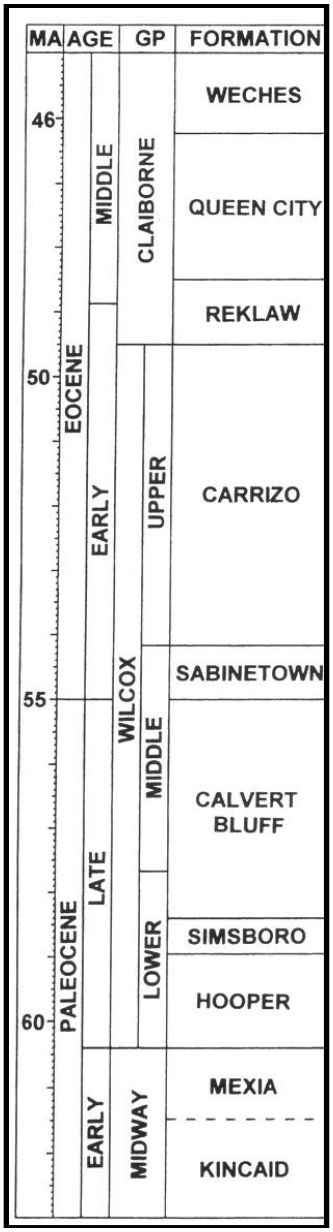


Figure 2. Paleogene formations of the upper coastal plains of Texas.

Strata present in the Red Bluff section (Figure 3), although part of the Wilcox Group, contain sediments deposited in a marine environment (Dickey and Yancey, 2010; Yancey et al., 2010; Yancey et al., 2012) that does not fit in the Mt. Pleasant or Rockdale systems described by Fisher and McGowen (1969). Strata exposed at Red Bluff beside the Colorado River contain marine dinoflagellates (Dickey and Yancey, 2010) and underlying strata of the upper Calvert Bluff Formation contain marine invertebrates and vertebrates (Yancey et al., 2012). Strata of the upper Calvert Bluff Formation are part of the Sabinetown transgression, a pre-Carrizo event that reset the pattern of depositional systems of older parts of the Wilcox Group. These marine upper Calvert Bluff deposits sit atop sediments of the Rockdale delta system on the northern part of the south Texas shelf system (Yancey et al, 2012), a relationship indicated in the work of Kaiser (1978). Gardner (1924) also reported the presence of outcropping Sabinetown transgression marine deposits with macrofossils in an area near San Antonio.

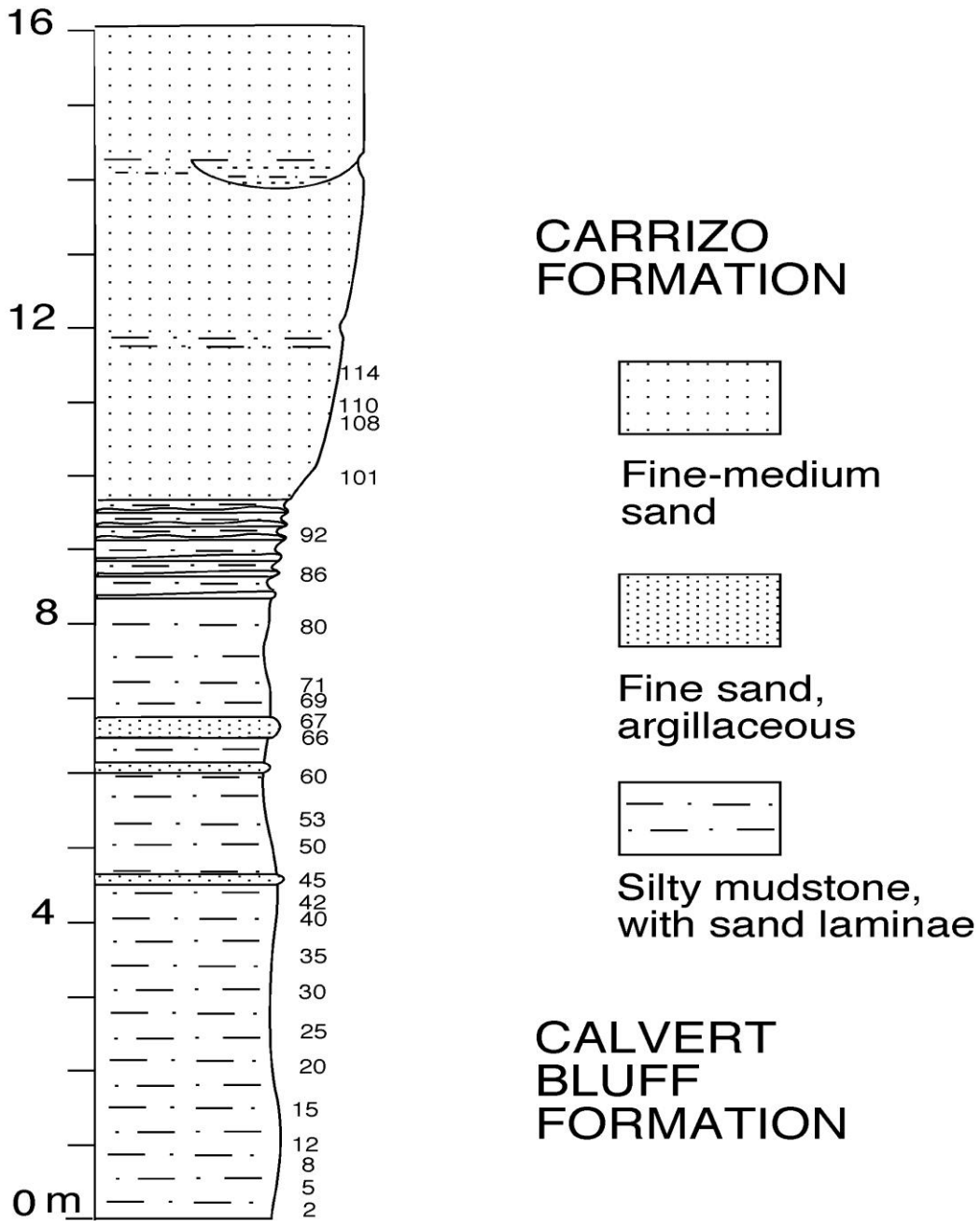


Figure 3. Red Bluff section of the Calvert Bluff and Carrizo formations at Red Bluff on the Colorado River, Bastrop County, Texas.

The upper Calvert Bluff Formation at Bastrop consists of mudstones and sandstones, exposed in two major locations: the Red Bluff section and the 71-21 section. Strata in both sections have laterally extensive planar bedding that can be traced to the limits of exposure and have sedimentary structures and trace fossils indicative of marine deposition. Strata in the Red Bluff section contain marine microfossils. The Red Bluff section is a major set of exposures on the north bank of the Colorado River where resistant sandstones of the Carrizo Formation provide support for high bluffs beside the river.

The 71-21 section is in an area of excavations at the junction of Highways 71 and 21 (Figure 4) that have remained exposed for nearly two decades. It exposes strata of the upper Calvert Bluff Formation that are older than those in the Red Bluff section. The 71-21 site contains a maximum flooding surface (with a marine hardground) and the condensed zone of the Sabinetown transgression, resting on a thick marine sandstone and overlain by an upward-coarsening set of mudstones and sandstones. Strata enclosing the maximum flooding surface contain marine macrofossils, shark teeth, and test linings of foraminiferans, indicating an open marine environment. Sandstones in the upper part of the 71-21 section contain abundant carbonized wood and plant debris.

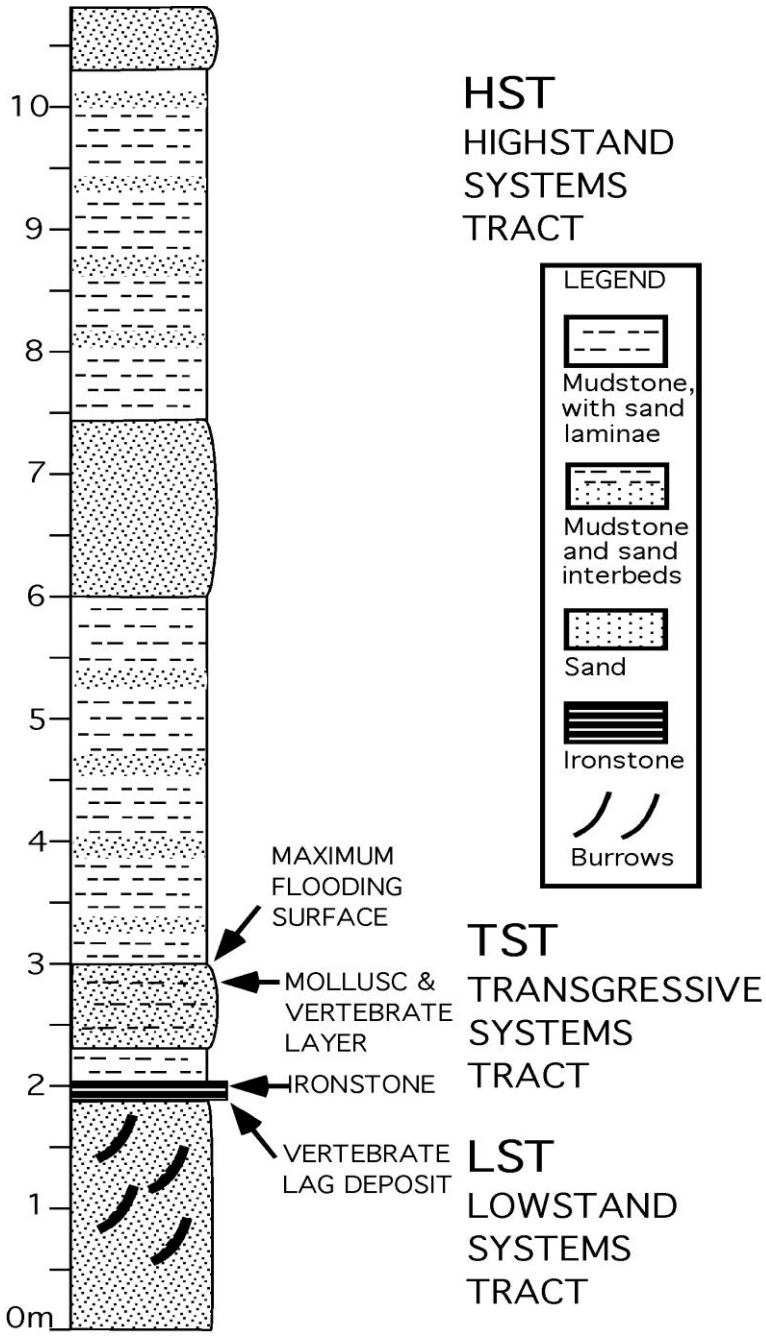


Figure 4. 71-21 section of the upper Calvert Bluff Formation at junction of routes 71 and 21 in east Bastrop town, Bastrop County, Texas.

The Red Bluff section at the top of the Calvert Bluff formation is an upward-coarsening section of mudstone with little or no sand overlain by a 3 m thick interval of alternating mudstone and sandstone that in turn is overlain by 18 m of well sorted sandstone that forms the Carrizo Formation (Figure 5). Strata within the transition from mudstone to sandstone in the Red Bluff section (6-10 m level in Figure 4) contain hummocky storm sand deposits in the lower part and tidalite structures in the upper part. The grain size trend and sedimentary structures of the deposits is typical of regressive shoaling deposits that here culminate in the paleosol exposure horizon within the lower part of the Carrizo Formation.

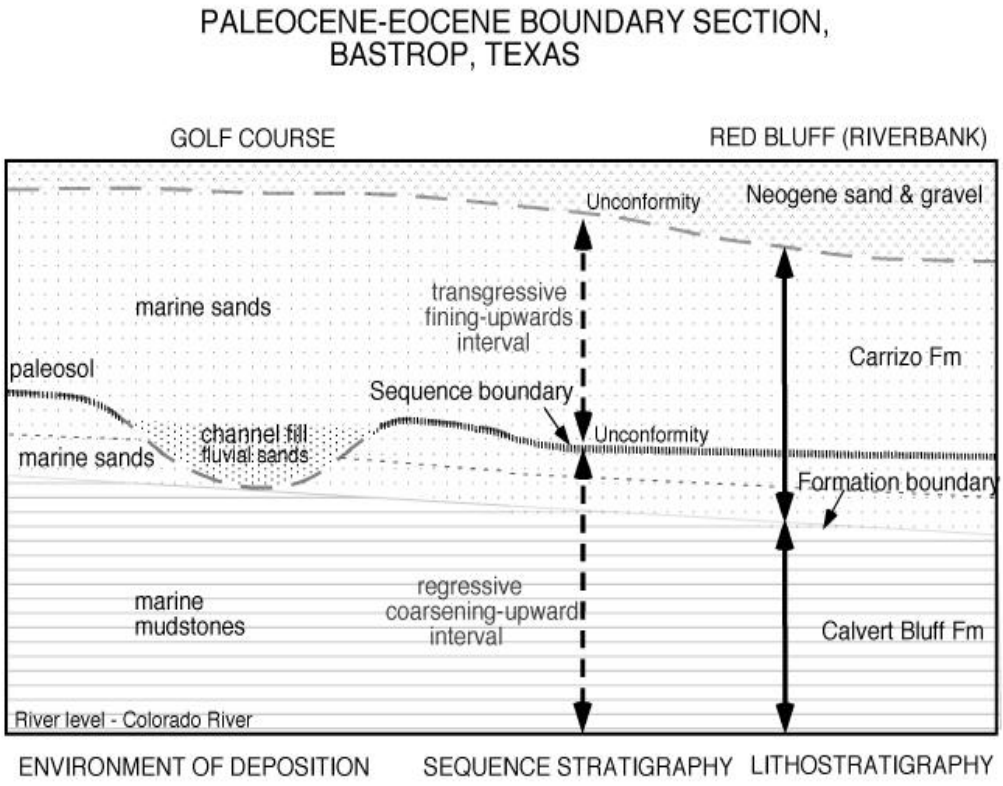


Figure 5. Sequence stratigraphy of the Red Bluff section, Bastrop County, Texas.

An exposure horizon with a well-developed paleosol is present in the lower part of the Carrizo Formation. The exposure horizon is cut out by a small channel fill in an area along the edge of the Pine Forest golf club. The channel cuts down from the paleosol, cutting lowest Carrizo strata and into the transition zone from Calvert Bluff mudstones to Carrizo sandstone. The channel is filled with four distinct packages of sands and sandy muds, of which three have lateral continuity across the the width of the channel (Yancey et al., 2010). Water escape structures and pockets of mud with distinct leaf impressions and plant macrofossils indicate highly variable water flow conditions within the small

channel. The channel is capped by a layer that appears to be a lignite and at one time contained a silicified log. However, the sediment is very sandy and unconsolidated. Microscopic analysis shows that the sediment is a mixture of sand similar to the Carrizo sand containing large amounts of wood and charcoal particles (Yancey et al., 2010).

Calvert Bluff strata consist of shoaling-upwards, fine-grained, shallow marine deposits of a highstand systems tract (HST), whereas Carrizo strata consist of well-sorted, shallow marine deposits of a transgressive systems tract (TST) (Figure 5). A sequence boundary occurs within the lower Carrizo Formation at the top of a paleosol extending over the 500 m (1,640 ft) length of the study area. The mud content of the paleosol decreases downward in a manner consistent with secondary infiltration of clay into sand during time of exposure and soil development. This unconformity (sequence boundary) occurs several meters above the lithologic boundary between the Carrizo and Calvert Bluff near the west end of the study area. The sequence boundary dips down to the base of a small, incised channel that is cut into underlying strata (Figure 5). This channel complex cuts through the paleosol and lowest sand strata of the Carrizo and is bounded below by the more resistant marine mudstones of the Calvert Bluff Formation.

Previous palynological sampling of the Red Bluff section of Wilcox Group strata beside the Colorado River and the Pine Forest Golf Course near Bastrop, Texas, indicated the possibility of deposits spanning the Paleocene-Eocene boundary at or near the boundary between the Calvert Bluff and Carrizo formations. Strata at the top of the Calvert Bluff Fm. yielded a Late Paleocene age determination (Jardine and Harrington, 2008) or basal Eocene age determination (Elsik and Crabaugh, 2001), and sparse Early

Eocene dinoflagellates, including the presence of *Apectodinium homomorphum* and *Wetzeliella* spp. *(articulata* group) are reported from a nearby upper Carrizo Fm. deposits (determination by J. Stein, 2007). An Eocene age for the Carrizo Fm. agrees with other work placing it in the Early Eocene (Brown and Loucks, 2009; Xue and Galloway, 1995, and many other references). Xue and Galloway (1995) correlate the base of the Carrizo Fm. with microfossil zone P6. With this guidance, palynological sampling work started in an attempt to determine the horizon of the Paleocene-Eocene Thermal Maximum (PETM) interval, the marker for the beginning of the Eocene.

The palynological study interval of this report spans the highest part of the Calvert Bluff Formation and lowest part of the Carrizo Formation. Palynological sampling covered a 30 m (99 ft) section of Calvert Bluff and Carrizo strata (Figure 3).

CHAPTER III

METHODS

Palynological samples for this study were obtained from a stratigraphic interval inclusive of the Sabinetown transgression from the uppermost part of the Calvert Bluff Formation, and from basal sediments of the Carrizo Formation. Mudstones of the uppermost Calvert Bluff Formation, exposed in the Red Bluff section, provided most of the microfossils used in this study, whereas sandy sediments of the Sabinetown transgression and basal Carrizo Formation produced abundant plant detritus, but few pollen grains. Sampling was done on stratigraphic sections exposed at Red Bluff on the banks of the Colorado River, located beside the Pine Forest Golf Club in the Tahitian Village subdivision, and the intersection of Rts. 71 and 21 in the city of Bastrop.

Samples were taken in 10 cm increments from the base of the section and extending upwards after cleaning away weathered material to expose fresh undisturbed sediment. 50-100 grams of material were taken for each sample and placed in sealable plastic bags for transport to the lab. These measures were taken to ensure minimal exposure to modern contaminants (pollen, dust, etc.) prior to processing. In the lab, 20 gm samples were split from the bulk sample for palynomorph processing.

Sample preparation follows standard palynological processing techniques. Twenty grams by weight of each sample were gently crushed and placed into plastic beakers. Tracer *Lycopodium* spores were added to each sample to aid in abundance counts and to check the quality of processing. Multi-day processing for extraction of

palynomorphs started with soaking in a sodium hexametaphosphate and water solution to produce disaggregation of the clay minerals.

Carbonate minerals were removed by soaking each sample in a small amount (~5 ml) of hydrochloric acid (10%) diluted with 500 ml water for at least 3 hours. After siphoning off the HCl and water solution, 50 ml of 49% hydrofluoric acid were added to each beaker in order to remove silicates. The HF was left in the beakers for a minimum of 8 hours and up to 24 hours and then diluted with roughly 450 ml of water. This solution was allowed to settle for 3 hours, siphoned off and the cycle was repeated again. At this point, the residue from each beaker was transferred to a sterile 15 ml test tube and rinsed with HCl three times. After the HCl rinses, each sample was rinsed in water, centrifuged and decanted until the water became clear. The samples were next treated to acetolysis, requiring that all water be removed from the samples in order to avoid a dangerous chemical reaction. Therefore, the test tubes were placed in the fume hood without their tops to allow any excess water to evaporate. Acetolysis was performed by heating the sample with sulfuric acid and acetic anhydride to oxidize any excess organic matter (plant tissue, woody particles). The process is highly corrosive to the cellulose in plant tissues, but if done carefully and for a short period of time, will not damage the sporopollenin in the palynomorphs. Exactly 35 ml of acetic anhydride were placed in a clean and dry glass beaker. To this, 5 ml of sulfuric acid were slowly added and stirred with a glass rod. Five ml of this mixture were carefully mixed into each sample. The test tubes were placed into a heating block for 7 minutes to speed up the chemical reaction. After the tubes were removed from the heating block, glacial acetic acid was added to each in order to stop the

reaction. The tubes were then centrifuged and decanted and more glacial acetic acid added to ensure that the reaction was stopped. After a second decanting, three water rinses were done.

After treatment with chemicals to extract the palynomorphs, heavy density separation allowed the pollen and other lighter fraction palynomorphs to separate from the heavier remaining matrix. Between 5 and 7 ml of zinc bromide (ZnBr) of specific gravity 2.0 were mixed thoroughly with each sample, and 1 ml of ethanol and 2 ml of water were gently added on top of the ZnBr. The tubes were centrifuged on lowest speed for 5 minutes and then at 90% speed for 2 minutes. Upon removal from the centrifuge, the pollen was drawn off with a pipette and placed into a new sterile test tube. The original tubes were spun down once again and the pollen drawn off to ensure maximum pollen recovery. Once the pollen was recovered, it was washed in ethanol three times to stop any reaction with the ZnBr. Then, 2 drops of safranin stain were added to each tube, along with 10 ml of water. The tubes were again spun down, decanted, and rinsed with ethanol. The pollen residue was then transferred to sterile 2 ml tubes, spun down and decanted and 2 drops of glycerol were added to the stained residue.

After mixing the residue thoroughly with a vortex mixer, slides were made by placing a small amount of the residue on a slide with a toothpick. An additional drop of glycerol was mixed into the residue on the slide and a slide cover placed on top. Clear nail polish was painted along the perimeter of the slide cover to seal it.

Slide counts were done by counting a minimum of 300 grains per slide. If a taxon was present in abundances of more than 30% of the assemblage, an additional 100 grains

were counted to get a better representation of the assemblage. After completing a count, the rest of the slide was examined for any new or rare forms or general observations.

Additional splits of many samples were made to concentrate and locate any dinoflagellates present in the samples and maximize their recovery. Chemical and mechanical processing techniques were reduced in order to limit damage to the cysts. Processing was completed with only hydrochloric and hydrofluoric acids and water rinses. Each sample was sieved through a 40 micron screen in order to concentrate the larger fraction palynomorphs. Acetolysis was not done, as it is corrosive to organic material and could have damaged the more delicate dinoflagellates. Tracer spores of *Lycopodium* were added to check for quality of processing.

Slide counts and specimen identification were done using a Nikon Alphaphot compound microscope at 20x. For photographing specimens, I used a Leica light microscope with top-mounted camera attachment that utilized Spot Advanced imaging software. Occasionally, Differential Interference Contrast microscopy was the technique of choice on this scope in order to look at finer detail on some palynomorphs.

In terms of nomenclature, fossil palynomorphs are often identified down to the family or genus level, and even then many names are based on assumption about the genus or family origin of the plant producing the pollen. In fact, even most extant pollen is known only by genus (Traverse, 2007). Macrofossils of flowers or cones are rarely found, making it difficult to make definitive identifications of palynomorphs beyond the family or genus level; hence using a form-genus name is commonplace. Comparisons

are often made to extant pollen taxa, but this may not be accurate due to mosaic evolution (Traverse, 2007).

Statistical analysis was made with the PAST (PAleontological STatistics) program created by Øyvind Hammer, Natural History Museum, University of Oslo. Ordination and cluster analyses were done using pollen only, eliminating taxa with only occurrence. Some samples contain dinoflagellate cysts; however the distribution of dinoflagellate cysts, which formed in the marine water column, reflect marine conditions and transport mechanisms, rather than changes in the terrestrial environment.

CHAPTER IV

RESULTS

Palynology data and data on organic carbon (TOC), nitrogen (N), and carbon (C) isotopes are presented for the upper Calvert Bluff Formation and lower Carrizo Formation. Upper Calvert Bluff samples are from the riverbank portion of the Red Bluff section and samples of the lower Carrizo Formation are from exposures of the adjacent road cut and nearby Cart Path outcrops. Multiple attempts were made to recover pollen and spores or dinoflagellates in samples of the 71-21 section, but very few palynomorphs were recovered and those recovered are too poorly preserved to be identifiable.

Palynomorphs were recovered from 42 Calvert Bluff samples, containing 75 identified taxa. This includes 52 types of pollen, 6 spores, 4 algal cysts, 11 fungi, and 2 dinoflagellates (Figure 6). Five samples of the basal channel fill deposit of the Carrizo Formation contain 10 types of pollen, algal cysts, and fungal spores (Figure 7). The majority of organic fossil material collected in the Carrizo Formation consists of wood debris. Pollen and spores deposited in the sands of the Carrizo Formation are lost to oxidation.

		SAMPLE NUMBER										
TAXON	**GROUP**	**2**	**4**	**5**	**8**	**10**	**12**	**15**	**18**	**20**	**21**	**23**
Thompsonipollis magnificus	angio-order unknown	7	5	11	7	6	7	7	11	9	11	2
Spineapollis spinosus	angio-order unknown	3	2	9	1	1	3	0	1	1	1	1
Pistilipollenites	angio-order unknown	0	0	2	0	0	1	2	1	1	1	0
Subtriporopollenites	angio-order unknown	13	11	0	21	23	15	1	0	0	0	4
Tricolpites	angio-order unknown	70	51	44	34	30	59	63	65	58	61	67
Insulapollenites	angio-order unknown	0	0	0	0	0	0	0	3	1	1	0
Quadrapollenites	angio-order unknown	0	0	1	2	2	1	3	0	1	1	0
Inaperturites	angio-order unknown	1	0	0	2	2	0	0	0	0	0	2
Triporopollenites	angio-order unknown	1	0	0	0	0	1	0	0	0	0	1
Liliaceae	monocot	6	2	3	6	3	6	6	2	1	0	9
Favitricolporites	magnoliid	2	2	0	4	5	2	0	6	4	4	3
Sedge	commelinid	0	0	0	0	0	0	0	0	0	0	0
Mauritiidites	commelinid	0	0	0	1	0	0	0	0	0	0	0
Arecaceae	commelinid	8	3	1	7	5	6	4	2	1	1	6
Alnus	rosid	3	0	0	0	0	1	0	0	0	0	1
Ulnus	rosid	1	1	0	0	0	2	3	5	1	1	0
Tricolporites	rosid	8	13	20	17	12	21	9	15	10	7	22
Carya	rosid	2	10	14	4	8	13	8	8	16	15	25
Nudopollis	rosid	0	0	0	2	0	0	0	0	0	0	2
Bagelopollis verrucatus	rosid	0	0	0	0	0	0	0	0	0	0	0
Trudopollis	rosid	0	0	0	0	0	0	0	0	0	0	0
Corylus	rosid	0	0	0	0	0	0	0	0	0	0	0
Castanea	rosid	1	0	0	0	0	0	0	0	0	0	0
Acacia	rosid	0	0	0	0	0	0	0	0	0	0	0
Pterocarya	rosid	0	0	0	0	0	0	0	0	1	1	0
Basopollis	rosid	0	0	0	0	1	0	0	0	0	0	0
Cupuliferopollenites	rosid	14	8	1	7	7	4	0	5	7	6	4

Figure 6. Point counts of palynomorphs in Red Bluff section samples, edited for point count tabulation. Full data set presented in Appendix.

	lower	middle	upper
Taxodium	P	A	P
Favitricolporites	P	A	A
Nyssa	P	A	P
Carya	P	A	A
Maceopollenites	P	A	A
Plicatopollis	P	A	A
Botryococcus	P	A	A
Tetraporina	A	P	P
Schizosporis	P	P	P
algal cysts undiff	P	P	P
fungal spores undiff	P	P	A

Figure 7. Presence/absence tabulation of palynomorphs present in channel fill samples on Cart Path site at 14 m level in Red Bluff section, Bastrop, Texas. P = present; A = absent.

Measures of organic carbon ($\delta^{13}C$), percent organic C (% ^{org}C), and percent nitrogen (% N) were taken on 41 samples of the Calvert Bluff Formation in the Red Bluff section (Figures 8– 10B). Carbon and isotope analyses were done with the direction of Dr. E. Grossman on samples collected for the study of palynology.

Identifier 1	#	%N	d15N	%C	d13C VPDB	SD %N	SD d15N	SD %C	SD d13C
black-top	TOP	0.64	1.6	19.39	-25.91				
black-middle	MIDDLE	1.18	1.7	43.30	-25.14				
black-bottom	BOTTOM	1.26	2.6	42.03	-27.14				
RB01	1	0.06	3.4	1.28	-26.46				
RB04	4	0.06	2.7	1.37	-26.25	0.00	0.95	0.07	0.02
RB09	9	0.06	3.3	1.15	-26.37	0.00	0.12	0.04	0.09
RB-12	12	0.05	2.7	1.11	-26.45				
RB16	16	0.05	2.4	0.97	-26.37				
RB-18	18	0.05	3.0	1.04	-26.54				
RB21	21	0.05	2.7	0.85	-26.36				
RB24	24	0.06	2.7	1.47	-26.45				
RB27	27	0.06	1.9	1.13	-26.63				
RB30	30	0.04	1.2	0.79	-26.34				
RB31	31	0.063	3.5	1.41	-26.24				
RB-33	33	0.06	2.6	1.18	-26.65				
RB36	36	0.06	3.0	1.22	-26.65				
RB39	39	0.04	1.5	0.99	-26.93				
RB40	40	0.06	1.8	1.00	-25.98				
RB41	41	0.06	2.9	0.92	-25.73				
RB44	44	0.03		0.48	-25.90				
RB46	46	0.01		0.11	-25.58				
RB47	47	0.04	2.8	0.52	-25.71				
RB50	50	0.04	1.3	0.82	-26.35	0.00	1.22	0.09	0.02
RB-53	53	0.05	2.5	1.04	-26.62				
RB56	56	0.05	1.9	1.22	-26.43				
RB59	59	0.06	1.5	1.50	-26.83				
RB61	61	0.04	2.9	0.90	-26.40	0.00	0.65	0.01	0.01
RB65	65	0.05	2.2	1.28	-26.59				
RB67	67	0.05	2.0	1.30					
RB71	71	0.06	3.7	1.31	-26.41				
RB73	73	0.059	3.4	1.08	-25.95				
RB80	80	0.06	2.2	1.13	-26.04	0.02	0.73	0.20	0.09
RB83	83	0.06	3.2	1.32	-25.21				
RB85	85	0.034	3.2	0.35	-25.18				
RB86	86	0.03	4.2	0.50	-25.73				
RB-89	89	0.02	0.6	0.34	-25.56				
RB92	92	0.03	2.8	0.65	-25.20				
RB98	98	0.04	2.4	0.77	-26.10				
RB101	101	0.07	2.2	2.00	-26.41				
RB104	104	0.02	2.8	0.26	-25.29				
RB108A	108	0.02	3.0	0.30	-25.13				
RB110	110	0.028	3.4	0.44	-25.36				
RB111	111	0.02	3.4	0.33	-25.00				
RB114	114	0.04	2.8	0.46	-25.30				

Figure 8. Data set of nitrogen and organic carbon content and isotope composition of palynomorph-bearing samples in the Red Bluff section, Bastrop, Texas.

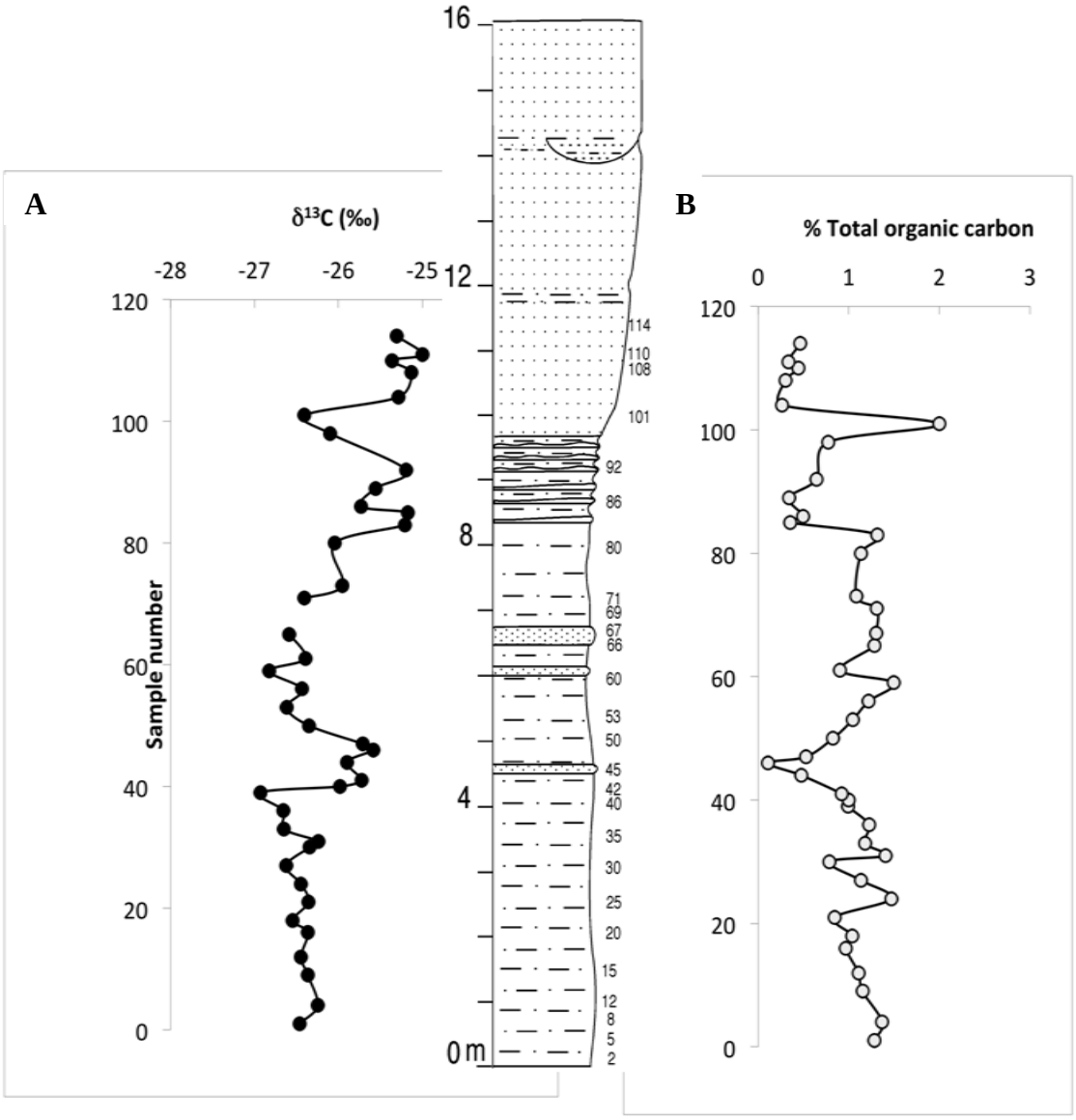


Figure 9. Plots of carbon isotopes (A) and total organic carbon (B) in Calvert Bluff samples in the Red Bluff section, Bastrop, Texas.

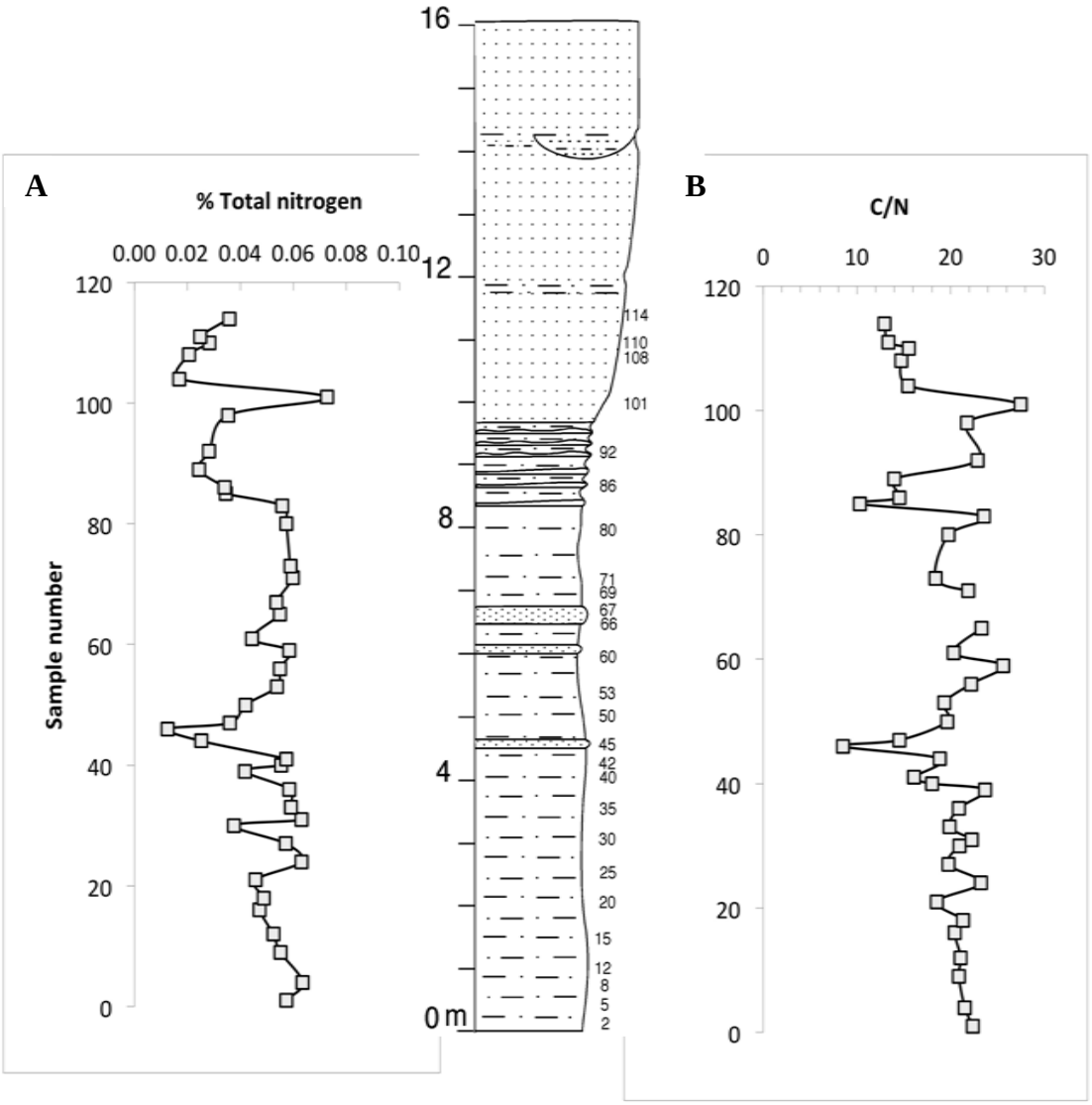


Figure 10. Plots of total nitrogen content (A) and C/N ratio (B) in Calvert Bluff samples in the Red Bluff section, Bastrop, Texas.

Detrended correspondence analysis divides the palynology data set into a few taxonomic assemblages that separate along the X and Y axes (Figure 11). The *Apectodinium homomorphum* and *Cordosphaeridium* (Figures 12) plots are disregarded, being dinoflagellates that live within the water mass and not transported taxa. The main assemblage in the center of the plot contains all of the common taxa. A second distinct cluster is the *Castanea*, *Corylus*, sedge cluster on the right side of the plot. This is a tight cluster and the taxa occur in adjacent stratigraphic samples within a distinct lithology. This is a well determined assemblage of palynomorphs, similar to the Marine Influence Assemblage of Nichols and Traverse. A third "cluster" is the *Lythraceae/Sonneratia* point that is separated from the other taxa. It has ecological significance, being a distinct mangrove indicator, making it an interesting data point.

The remaining peripherals group as either "high peripherals" (plotting higher on Axis 2 than the main cluster) or "low peripherals" (plotting lower on Axis 2 than the main cluster). These peripheral groupings contain the most interesting taxa in this study. With multidimensional analysis ordination (Figure 13), the main assemblage can be subdivided into two subjective clusters of taxa. This is supported by two-way clustering of taxa and samples that show a clear separation (see supplemental file). Only 3 samples plot away from the main clusters, these being the 66 and 67 *Castanea/Corylus*/sedge samples, and Sample 15. Sample 15 is unique because it contains higher numbers of *Platycarya, Taxodium*, and algae than any other sample and has quite low numbers of *Betula/Myrica*. The *Taxodium* and algae indicate a more swamp-like freshwater setting. Typically, *Betula/Myrica* would be in abundance as well in a swamp. *Platycarya* is very

high in this sample, indicating the possibility of it being adapted to a swamp-like environment. Harrington (2008) noted this anomalous *Platycarya* occurrence in his study of Eastern Gulf of Mexico swamp sediments, attributing the high abundance to a true local occurrence and not transport. The appearance of a swamp assemblage in the section may point to a recording a flood event that flushed swamp waters out into the ocean.

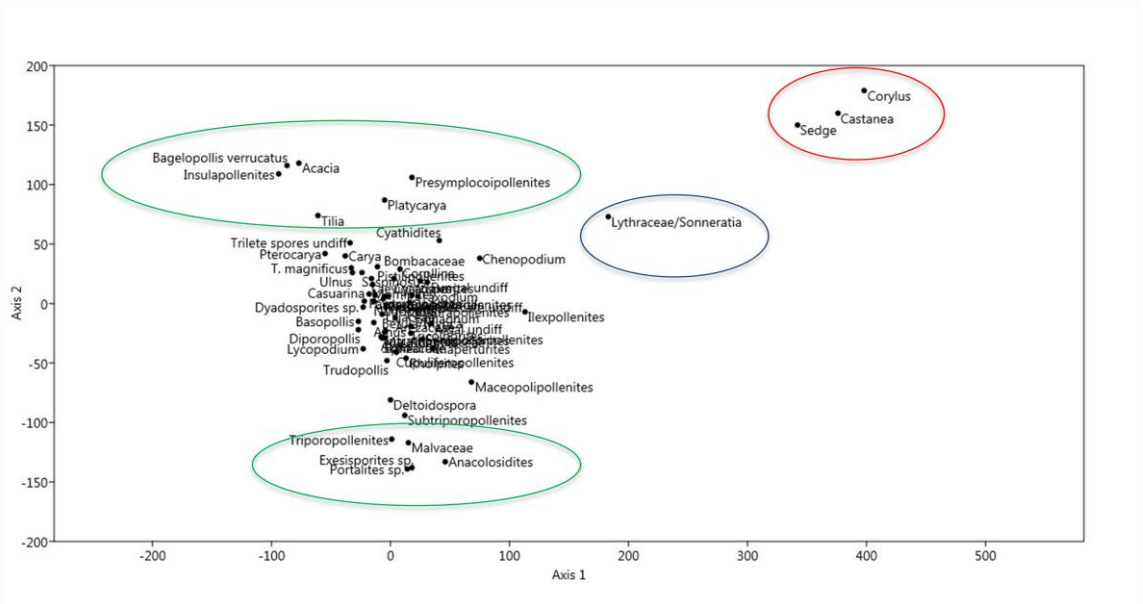


Figure 11. Detrended correspondence analysis of palynomorph taxa in samples of Calvert Bluff Formation in the Red Bluff section, Bastrop, Texas.

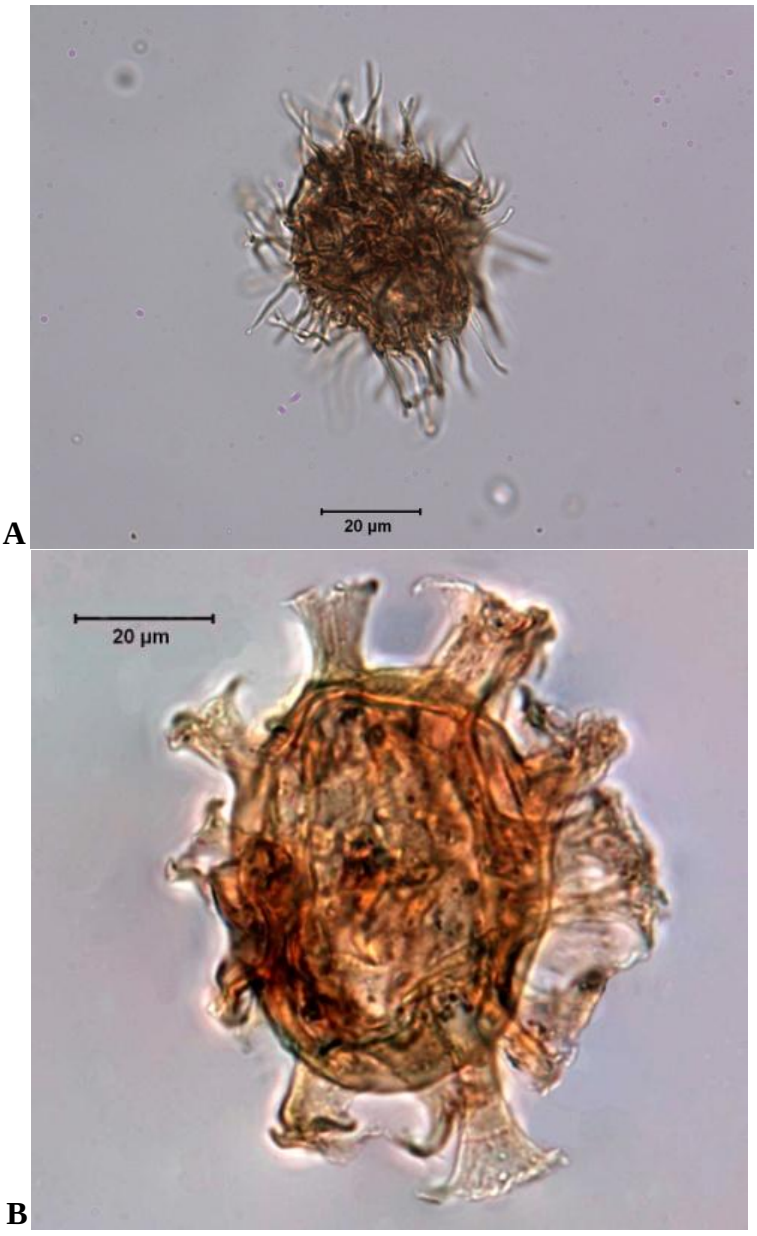


Figure 12. *Apectodinium homomorphum* (A), *Cordosphaeridium* (B).

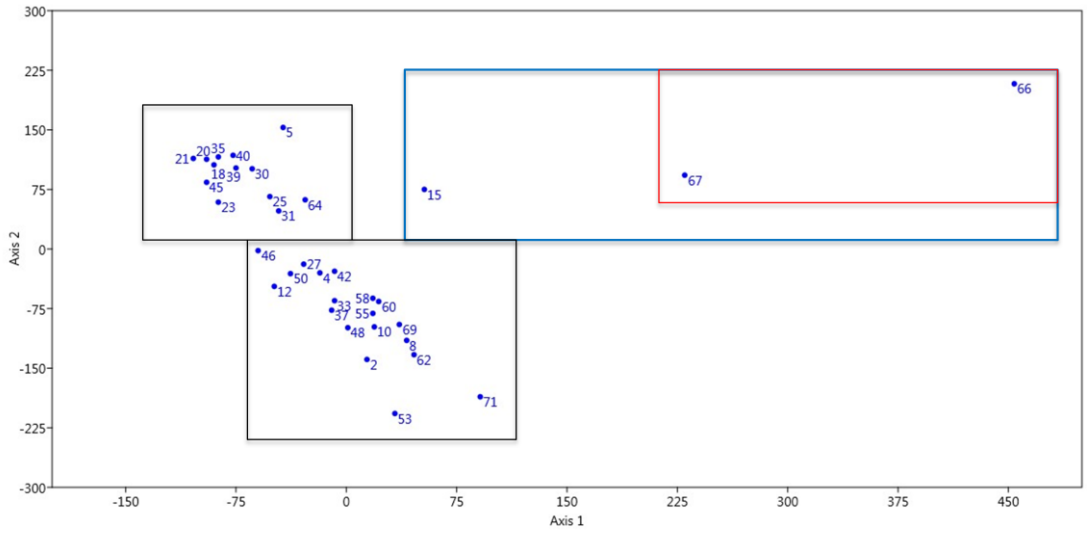


Figure 13. Multidimensional analysis ordination along the X axis of palynomorph samples of the Calvert Bluff Formation in the Red Bluff section, Bastrop, Texas.

AGE-DETERMINANT POLLEN

The results of this study reveal the presence of Eocene indicator palynomorphs throughout the Red Bluff section. These taxa include pollen taxa *Platycarya, Sonneratia, Symplocoipollenites, Bagelopollis verrucatus, Anacolosidites, Ilexpollenites, Intratriporopollenites instructus* and dinoflagellate taxon *Apectodinium homomorphum* (Figures 14A-G, Figure 12A.).

Platycarya (Figure 14A) is a deciduous tree of the Juglandaceae (walnut) family native to Asia that migrated into North America during PETM.

A *Platycarya* spike can be seen in many regions in samples from the beginning of and during the PETM. It is thus a pollen marker for the base of the Eocene in North America. In this study, *Platycarya* does not present itself as a flood or distinct spike in the samples. It is, however, present in appreciable numbers in sample 5 and is most abundant in sample 15 of the Red Bluff section.

Crabaugh and Elsik (2000) and Harrington and Jaramillo (2007) note that the *Platycarya* FAD for the Gulf Coast corresponds with the Paleocene-Eocene boundary, when the taxon spread out of Asia and there is a *Platycarya* spike in PETM deposits. Although *Platycarya* appears only as a minor component in shallow marine deposits of the northern Gulf of Mexico region, its appearance marks the beginning of the Eocene.

Bagelopollis verrucatus (Figure 14B) is a taxon with a unique morphology and very short age range, making it an important biostratigraphic marker (Carroll, 1999). The genus was named by Carroll for a species placed in *Corsinipollenites* by Fredericksen (1988) known from lignite beds in the Tuscahoma Formation. The difference between *Corsinipollenites* and *Bagelopollis* is that the former has a thickening in the endexine of the annulus (Jansonius and Hills, 1976) while the latter has an ektexinal thickening of what is termed a pseudo-annulus (Carroll, 1999). In four published reports citing the occurrence of *Bagelopollis verrucatus*, all identify the age of the strata as being at the Paleocene-Eocene boundary or latest Paleocene/earliest Eocene. Citation of the less definite latest Paleocene/earliest Eocene age is the result of

changing opinions on the placement of the Paleocene/Eocene boundary and the continuing uncertainty on this matter.

The unique combination of pseudo-annulae and the verrucae on the annulae of *Bagelopollis* is not recognized in any extant taxa (Carroll, 1999). This makes it difficult to relate it to a particular known family (Carroll, 1999). *Corsinipollenites* has an affinity with the Onagraceae family (Zetter and Keri, 1987).The environment of *Bagelopollis* can be inferred from the lithology of the source samples. In Carroll's study (Carroll, 1999), pollen were restricted to swamp-type environments, specifically "…well-flooded, fresh water swamp with an overstory of Betulacean and Myricacean trees and and understory dominated by ferns". Carroll also concludes that it was insect or animal pollinated, based upon the scarceness of the grains within the samples as well as upon the morphology. Pollen with more texture and protrusions tend to be insect or animal pollinated, as this morphology allows the grains to be picked up by hair/fur.

Basal Eocene zones based on the appearance of the combination of *Bagelopollis* and *Spineapollis spinosus* for the northwestern Gulf of Mexico region were erected by Crabaugh and Elsik (2000) and Elsik and Crabaugh (2001). The Eocene age of these zones is now questioned (Harrington and Jaramillo, 2007; Jardine et al., 2012) based on stratigraphic ranges of the taxa in the eastern Gulf of Mexico, but there is a great difference in flora of the two regions that makes extension of pollen ranges from the eastern to northwestern regions risky without additional evidence to test them. Until this is clarified and doubt resolved, the zones should be accepted with caution.

Sonneratia spp. (Figure 14C) has not previously been described as occurring in

the northern Gulf of Mexico, either in the RHTS section or in the Harrell core, nor elsewhere in North America, but has an occurrence similar to that of *Platycarya*. It is know in Asia and India from the Eocene to present. W. Elsik (personal communication, 2010) identified *Sonneratia spp*. in the Red Bluff section and considered it another indicator of Eocene age in Wilcox Group strata.

Intratriporopollenites instructus (Figure 14D) found in the lower Eocene of the Powder River Basin (Tschudy 1976; Pocknall 1987; Harrington 2001b; Wing and Harrington 2001) also occurs in the Red Bluff section. Harrington identified this species in the younger Eocene aged Hatchitigbee of the Gulf Coastal Plain and also states that it is only one of two Eocene taxa found in both the continental interior and the coastal plain.

Symplocoipollenites (Figure 14E) is another pollen type that appears at the base of the Eocene. Harrington (2003) identified the *Symplocos*? *contracta* group as being new to North America beginning in the Eocene, although later disregarded it (and several other taxa) as an Eocene indicator when the RHTS section was set as containing the PETM (Beard, 2008; Harrington and Jaramillo, 2007). This decision is still in doubt (Fluegeman, 2012). Bill Elsik (personal communication, 2010) designated *Symplocoipollenites* as an Eocene indicator for the Red Bluff section and therefore for the northwestern Gulf of Mexico.

Anacolosidites sp (Figure 14F) and *Ilexpollenites* are both present in the Red Bluff section. *Anacolosidites* occurs in one of the higher samples. *Ilexpollenites* is present in eight samples throughout. *Anacolosidites sp.* has an early Eocene age (Elsik,

personal communication, 2012; Fairchild and Elsik, 1969), and *Ilex* occurs in uppermost Wilcox sediments (Fairchild and Elsik, 1969; Traverse, 2007).

The placement of this pollen relative to the horizon of the Paleocene/Eocene boundary has been refined by the study of the Harrell core at the Red Hot Truck Stop site, reported by Sluijs et al. (2014). That report set the P/E boundary at a level below the top of the Tuscahoma Formation, making the upper Tuscahoma basal Eocene in age. The Red Hot Truck Stop vertebrate fauna (Beard and Dawson, 2009) and leaf flora (Danehy et al., 2007) is therefore basal Eocene in age.

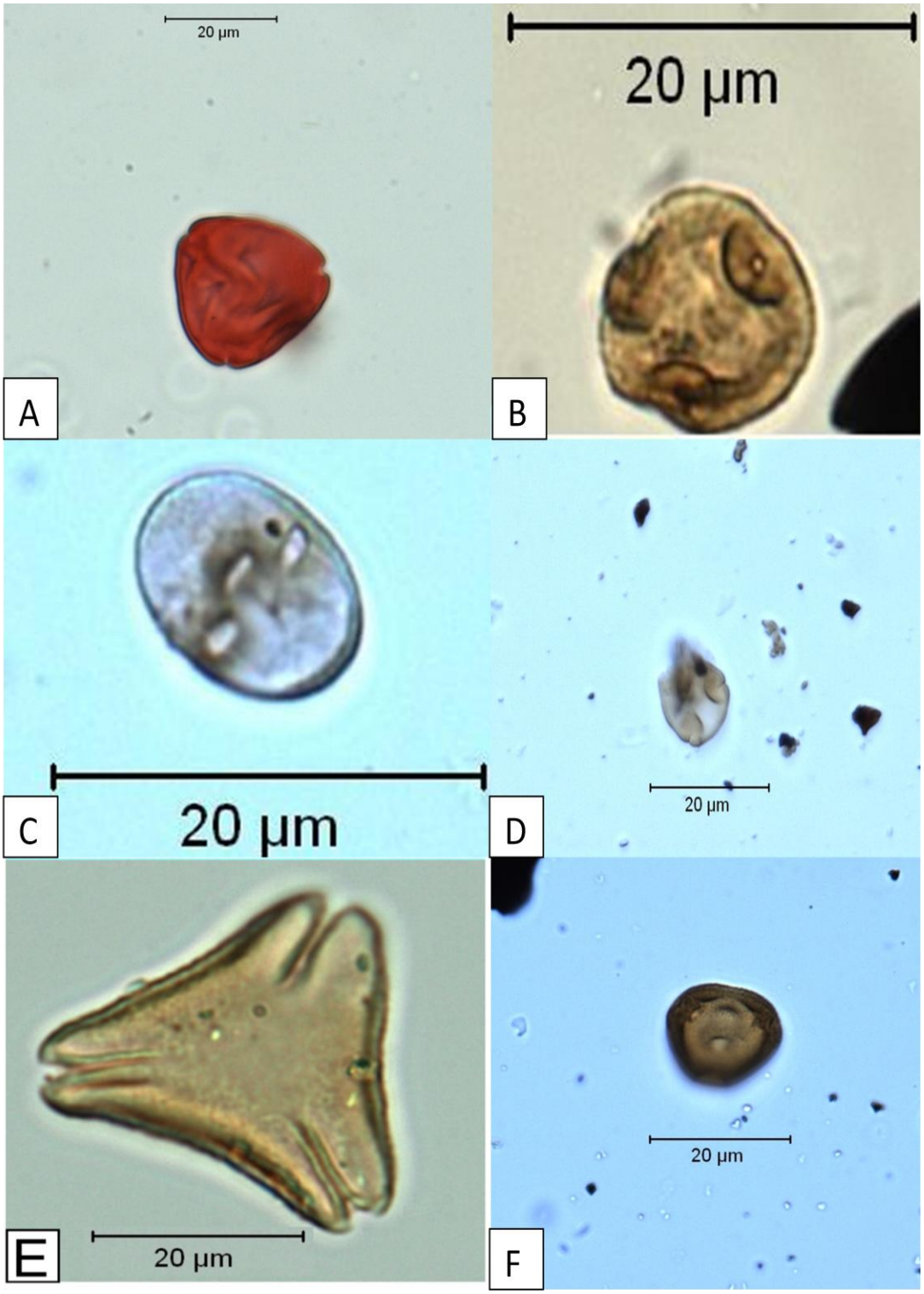
Apectodinium homomorphum (Figure 12A) was found in 3 samples within the Red Bluff. A "flood" or acme occurrence of this warm water dinoflagellate is a prime indicator for identifying the PETM (Sluijs et al, 2007), as an event that occurred in response to the rapid warming at the beginning of the PETM. This is a worldwide event that often occurs in association with a negative carbon isotope excursion. Demchuk et al. (2017) report a great abundance of *Apectodinium homomorphum* from the top of the Calvert Bluff Formation near the mouth of Copperas Creek as a site 0.3 km downriver from the Red Bluff section exposures.

A number of different fungal spores were recovered from the Red Bluff section of the Calvert Bluff, including *Didymoporisporinites sp., Exesisporites sp, Diporopollis sp., Foveodiporites sp., Diporicelasesporites sp., Diporisporites hamenii, Brachysisporites sp. Dyadosporites sp., Portalites sp., Pluricellaesporites sp.,* and

Fusiformisporites sp.. Traverse (2007) and Elsik identified *Fusiformisporites sp* and *Brachysporisporites sp.* as Eocene spores from his work in Texas. *Diporicellaesporites sp*. ranges from Late Paleocene to Eocene. *Portalites sp*. is noted from the Eocene of Arkansas.

Differences in regional flora between northwestern Gulf of Mexico and eastern Gulf of Mexico, separated by the Mississippi Embayment and lowlands, show up in differences in coeval pollen assemblages. This type of difference is noted for northern Gulf of Mexico region as a whole and the continental interior of North America and between northern Gulf of Mexico and South America (Harrington and Jaramillo, 2007).

Figure 14. Eocene indicator palynomorphs. A. *Platycarya sp.*, B. *Bagelopollis verrucatus,* C. *Sonneratia sp*., D. *Intratriporopollenites instructus,* E. *Symplocoipollenites,* F. *Anacolosidites*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CHAPTER V

DISCUSSION

Mudstones of the Calvert Bluff Formation yield the most abundant, diverse, and best preserved palynomorphs for the study. Muddy sandstones of the Carrizo Formation in the Road Cut and Cart Path portions of the Red Bluff section yield many small particles of wood and few poorly preserved pollen and spores, but they add some additional data to the study.

The 71-21 section is a stratigraphically lower section of the Red Bluff and is located 4.5 miles from the main Red Bluff. This section contains a marine flooding surface abundant in shark, skate and ray teeth (Yancey, et al. 2012). The overlying layers should contain pollen and spores similar to the Red Bluff, as well as an abundance of marine dinoflagellates, given that this would have been a deepwater environment of deposition. Samples from the 71-21 section collected several years before this study started were reported to have poor recovery with badly degraded specimens and fragments of a few dinoflagellates, so deeper sampling was done to obtain better recovery. A few degraded pollen grains of pine and *Chenopodium* were obtained in first collection 71-21 samples for this study, but none were found in later recollection. Pine is the ubiquitous tree of the Bastrop area and *Chenopodium* is a common disturbance taxon, raising the possibility of the pollen being modern contaminants, although Chenopodiacean pollen is reported to be a typical component of the Marine Influence Assemblage of Nichols and Traverse (1971). Re-collection of the section following

further excavation for construction work yielded no recovery of pollen, apparently due to increased surface oxidation in the porous, exposed strata and resulting in complete lack of recovery of palynomorphs.

Warm adapted to temperate dryland deciduous taxa are dominant vegetation type in the Red Bluff samples and fern spores are present in most samples. This relates to the role of water transport and wind transport in carrying pollen out to offshore locations before deposition. Large amounts of river-transported pollen can reveal much about the complete flora of a region with dryland flora that is rimmed by wetlands containing *Taxodium* and *Nyssa* and/or *Sonneratia* forests. A distinct spike in abundance of algae, ferns, and *Taxodium* pollen occurs at 6 meters above the base of the section, just above the level of a storm sand deposit contained within mudstones. This marks the base of the upward change in the palynomorph assemblage.

. Samples collected from Calvert Bluff strata in the Red Bluff section provide the primary data for age determination and interpretation of depositional environment. The dominant pollen present in Calvert Bluff samples are *Momipities* and *Tricolpites*, with substantial amounts of *Betula*/*Myrica*, *Tricolporites,* and *Subtriporopollenites,* and significant amounts of *Carya*, *Nyssa,* and *Taxodium* present (Figure 6, Figure 15, Appendix 1). Substantial amounts of fern spores, algal cysts, and fungal spores are also present through the section.

This is an assemblage dominated by trees or shrubs of Juglandacean, unknown dicotyledon, Betulacean, Ericacean, Cornacean, Arecacean (palm), and Cupressacean families. Understory plants are dominantly ferns.

A majority of the palynomorphs in the Red Bluff of the Calvert Bluff are aenomophilus including the Juglandaceous forms (*Carya sp.*, *Platycarya sp*.), *Myrica/Betula* and bisaccates, while ferns are carried by wind and/or water. Entomophilous or vertebrate animal pollination vectors are assigned to taxa such as *Pistillipollenites, Spineapollis spinosus*, palms, Bombacaceae, *Symplocoipollenites,* Ulmaceae, *Alnus* and *Intratriporopollenites instructus.*

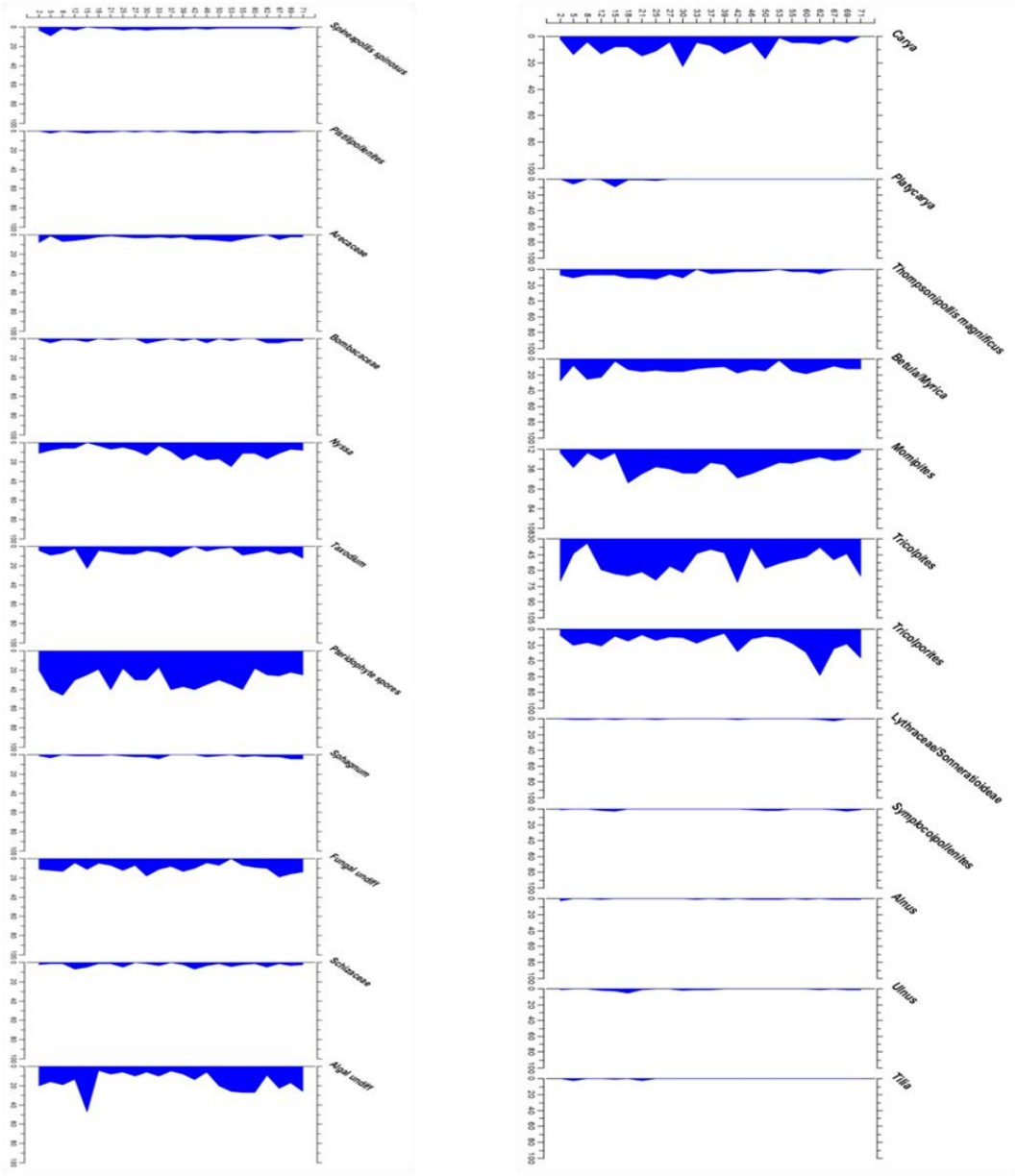

Figure 15. Dominant palynomorph taxa in Calvert Bluff samples in the Red Bluff section; plotted with C2 program of Steve Juggins, Newcastle University.

When the palynology data set is examined with statistical analysis, detrended correspondence analysis divides the taxa into a few distinct clusters (Figure 11). The primary cluster includes a large majority of the taxa and includes lowland taxa producing most of the pollen. Other clusters are peripheral to the primary cluster and include a well-defined tight cluster containing *Castanea*, *Corylus*, and Cyperaceae (sedge). A third cluster separates from the primary cluster along the Y axis of the DCA plotting; this includes most of the Eocene indicator taxa that occur primarily within the lower part of the section (implying age control).

Red Bluff palynomorphs fit into a Wilcox environmental assemblage recognized by Nichols and Traverse (1971) as the Marine Influence Assemblage, including dinoflagellates, bisaccate pollen, *Chenopodium*, and *Classopollis* (*Corollina*). In addition to *Classopollis* (*Corollina*) and ubiquitous *Taxodium*, gymnosperms present in the Calvert Bluff assemblage include tropical Cycadales and rare grains of temperate upland *Abies*. These are the pollen readily carried out to shallow ocean waters. This assemblage is similar to the Marine Assemblage 4 of O'Keefe et al. (2005), with more closed canopy taxa in it. The abundance of *Momipites* and *Betula/Myrica* in the Red Bluff samples indicates a large component of closed canopy lowland taxa being carried out to the ocean. The hardwood taxa are most typical of the basal lignite samples of lower Calvert Bluff Formation in northeast Texas (O'Keefe et al., 2005). This confirms that pollen samples of the Red Bluff section contain a mixture of ecological communities. They are also similar to the Early Eocene Wet Broadleaved Evergreen Lowland and the littoral *Taxodium* Ecological assemblages of Jolley and Spinner (1991)

in northern Europe. Within North Sea palynological successions, taxa of the Wet Broadleaved Evergreen Lowland assemblage gradually decrease upward as swamp taxa increase, a transition noted by Jolley and Morton (1992). The same pattern is seen in the Red Bluff.

The *Castanea*, *Corylus*, and Cyperaceae (sedge) assemblage is characterized by pollen having smooth, rounded grain shapes and occurs in fine-grained sand sediments. The grain shape differential and association with sand sediment suggests a strong influence of transport mechanism determining the assemblage. Rounded grain shape is also a characteristic feature of pollen and spores of the *Corylus*-*Sphagnum* assemblage of Nichols and Traverse (1971), although they report the *Corylus*-*Sphagnum* assemblage as occurring in primarily in lignites. In both cases, water transport processes appear to be a primary control on producing these assemblages.

The lower Y axis assemblage of Early Eocene taxa is part of the dispersed halo of associates of the main assemblage. The grouping below the main assemblage may be determined by the occurrence of most basal Eocene pollen in the lower part of the Red Bluff section. The assemblage has no obvious ecological significance other than its taxa being members of the secondary level of scarce pollen of the main assemblage.

Detrended correspondence analysis ordination of samples and Wards two-way clustering (see supplemental file) reveal a possible division within the main cluster of taxa that is suggestive of minor ecological settings within the lowland flora. A minor separation along the X axis appears on the ordination plot. Samples on the left side of the center point are from the mid interval of the Calvert Bluff section, whereas samples to the right tend occur more near the top or bottom of the section. There is no way to independently test this separation to determine if they are realistic clusters.

Depositional environment water energy levels exert a control on the pollen assemblage. There is a minor trend of decrease in diversity present in the highest samples (Figure 16), a trend that corresponds with an increase in sediment grain size due to a shoaling upward trend in deposition. This decrease correlates with an increasing mean grain size, associated with the presence of these sand/silt beds in the section.

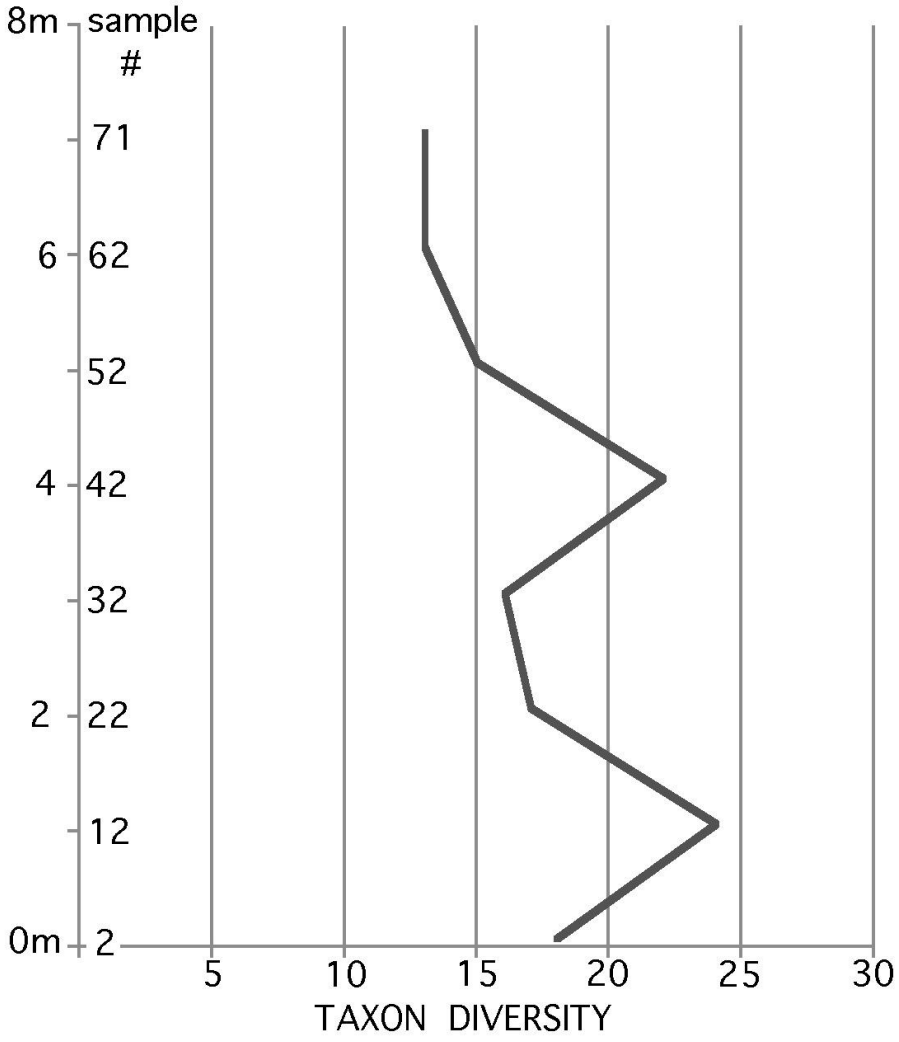

Figure 16. Diversity trend of palynomorphs in selected Calvert Bluff samples of the Red Bluff section.

There is also a gradual upward increase of freshwater and swamp/mangrove taxa (*Taxodium*, *Nyssa*, *Sonneratia* spp.) toward the top of the section that shows with increased *Nyssa*, freshwater algae, and fungal spore counts above the level of a storm sand deposit (6.7 m in section) contained within mudstones.

The palynomorph assemblages in this section are clastic sediment assemblages and are responsive to control by processes of moving water sediment deposition, in contrast to lignite assemblages that presumably are most strongly influenced by direct shed of pollen from local vegetation of the host swamp (Jardine and Harrington, 2008). Although some layers of Calvert Bluff and channel fill sediment have abundant wood debris, there are no samples containing pollen of a well vegetated swamp.

Separated from the Calvert Bluff samples by a sandstone and by an exposure horizon, there is a distinct fresh water environmental assemblage present in the channel fill deposits at the base of the Carrizo Formation (14 m on the Red Bluff section). This assemblage is dominated by algal cysts such as *Botryococcus*, along with some pollen including *Taxodium*, fungal spores, plant cuticle and woody debris, as well as broadleaf leaf fossils in marginal muds of the deposit. The taxa are only moderately preserved, reflecting the semi-porous character of the sandy mudstones that is probably responsible for the oxidation and degradation of pollen in these deposits. The pollen of the channel fill are indicative of a freshwater stream or bayou environment, a place where water movement is variable and includes quiet water phases with mud deposition. This channel fill is capped by a granular carbonaceous sand ("coffee grounds") containing abundant transported wood clasts of small size. This sand is quite loose and sooty, possibly

indicating runoff after a wildfire. Wildfire ecological disturbance would support the presence of fern taxa, as ferns are some of the first in ecological succession to recolonize an area after a catastrophic event (Collinson, 2003). This lignite-appearing sand contains an algal cyst-dominated assemblage similar to that in the underlying channel fill. The presence of common algal cysts and presence of whole leaf macrofossils in channel margin mudstones indicates deposition with a standing water environment, probably associated with flooding events. The presence of a capping carbonaceous sand indicates rising base level in association with transgression and flooding of the channel. Sands in the channel center contain water escape structures that reveal continued subbed water flow of fresh water until total filling of the channel occurred and Carrizo sands covered the channel. No age-diagnostic palynomorphs were recovered from the channel complex.

The Calvert Bluff Fm. at Red Bluff contains a zonal pollen assemblage of the *Thompsonipollis magnificus* megazone, a long-ranging zone that spans the Late Paleocene and Early Eocene (Fig. 17). Crabaugh and Elsik (2000) and Jardine and Harrington (2009) examined samples from Red Bluff outcrops and interpreted a Late Paleocene age for the highest part of the Calvert Bluff Fm. However, four of the over 75 palynomorphs in the Calvert Bluff Fm. are Early Eocene taxa in the zonation established by Elsik and Crabaugh (2001). Age diagnostic taxa include *Platycarya sp., Sonneratia, Symplocoipollenites, Bagelopollis verrucatus,* (Figure 14).

Eocene indicator taxa such as *Platycarya* have abundance peaks lower in the Red Bluff section, but are present throughout, though their numbers are never high. Elsik and Crabaugh (2001) defined a *Bagelopollis verrucatus* zone as a basal Eocene subzone within the *Spineapollis spinosus* zone. The *Bagelopollis verrucatus* zone occurs within strata of the Sabinetown transgression, a stratigraphic interval that occurs within the top of the Calvert Bluff Formation and underlies the Carrizo Formation in the Bastrop area (Yancey et al., 2012). This is compatible with an Early Eocene age for the overlying Carrizo Formation (Xue and Galloway, 1995; Brown and Loucks, 2009) that is placed within microfossil zone P6 (Xue and Galloway, 1995).

Studies of the Paleocene/Eocene boundary in North America have mostly been done on sections in continental interior Bighorn and Powder River Basins in Wyoming (e.g., Wing et al., 2003). Published studies of the P/E boundary in marine continental shelf sediments include southern New Jersey (Sluijs et al., 2007), Virginia (Edwards and Guex, 1996), and eastern Mississippi (Danehy et al., 2007; Sluijs et al., 2014). The eastern Mississippi site (known as Red Hot Truck Stop) is most comparable. Like Bastrop, it contains P/E strata deposited in shallow marine, inner shelf environments and is located within the northern part of the Gulf of Mexico basin.

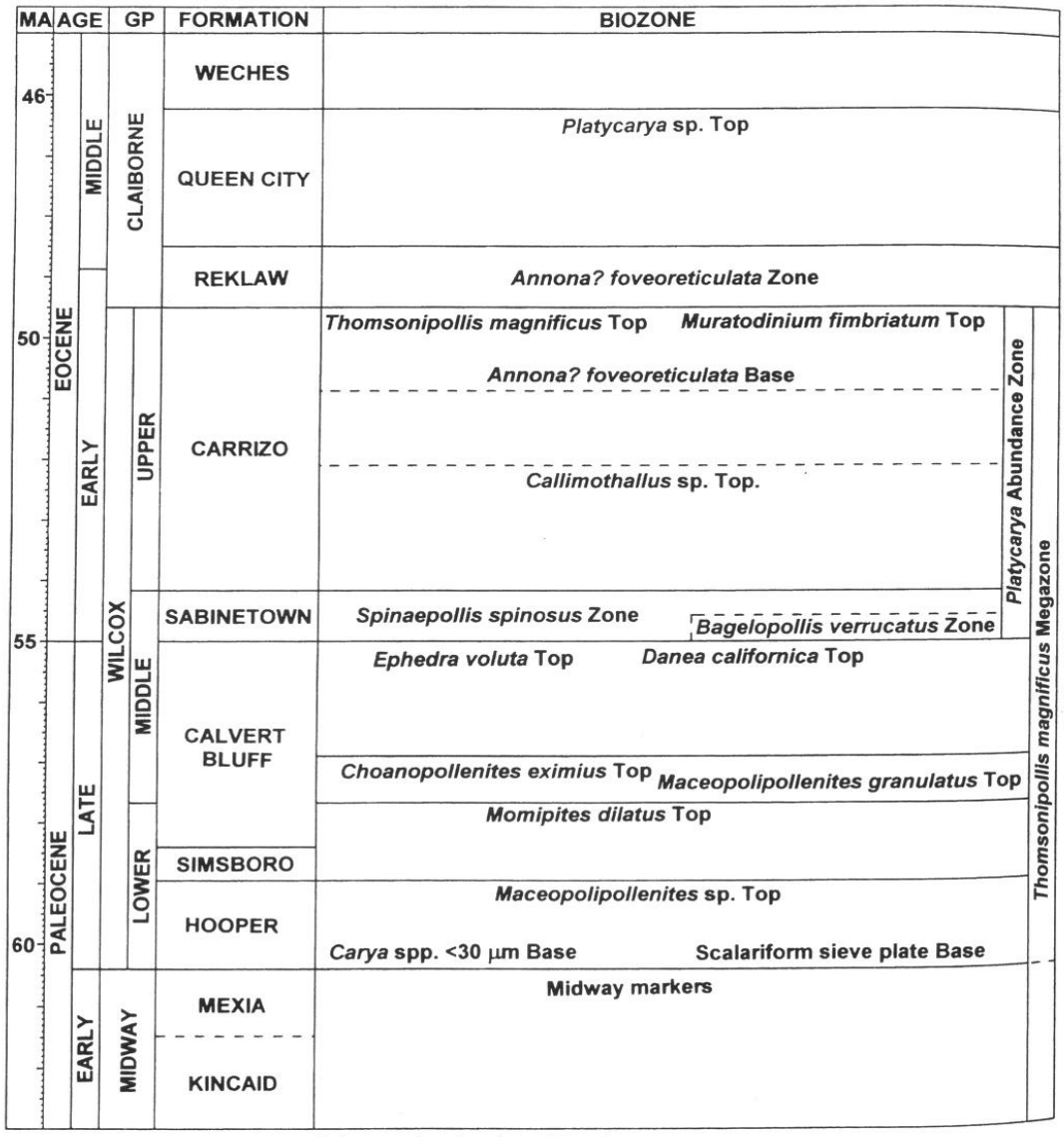

Figure 17. Palynology zonation of the Paleocene to Middle Eocene of the northern Gulf of Mexico region. From Elsik and Crabaugh (2001).

The Red Hot Truck Stop (RHTS) site includes an interval of Tuscahoma and Bashi formations (Case, 1994; Harrington et al., 2004; Danehy et al., 2007; Sluijs et al.,

2014) and the Harrell core sampled a thick section of upper Tuscahoma Formation. The sediments of the interval are similar to the Bastrop section, being of a coastal, inner shelf marine environment located at a similar latitude and in a similar paratropical climate. Harrington (2003) described the sediments at the RHTS site as being very similar to the sediments in Bastrop County, Texas, and identified 8 lower Eocene indicator taxa that are present in the Tuscahoma portion of the RHTS. Two of those are found in the Red Bluff section, *Platycarya* and *Symplocoipollenites. Intratriporopollenites instructus,* found in the lower Eocene of the Powder River Basin (Tschudy 1976; Pocknall 1987; Harrington 2001b; Wing and Harrington 2001) and the RHTS also occurs in the Red Bluff section. Harrington identified this species in the younger Eocene aged Hatchitigbee of the Gulf Coastal Plain and also states that it is only one of two taxa found in both the continental interior and the coastal plain. Many other Eocene taxa are shared between the RHTS section and the Calvert Bluff, including *Thompsonipollis magnificus*, Myricaceae/Betulaceae, *Cicatricosisporites*, Taxodiaceae, *Platycarya sp., Nudopollis, Tricolpites*, Taxodiaceae, *Nyssa, Deltoidospora, Caryapollenites* and others.

Sediments at RHTS are best known for containing a marine-dominated vertebrate fossil assemblage similar to the assemblage of marine vertebrates in the Calvert Bluff Formation at the 71-21 section (Yancey et al., 2012). Those vertebrate fossils allow the RHTS section to be correlated to the Eocene Wasatchian North American Land Mammal Age (NALMA) based on the occurrence of Wasatchian mammal teeth (Beard and

Dawson, 2009) and leaf flora (Danehy et al., 2007) and date the basal Bashi deposits as basal Eocene. Later work (Sluijs et al., 2014) placed the P/E boundary at a lower level within the Tuscahoma Formation. Fluegeman (2013) stated that the P/E boundary should be placed even lower in the Tuscahoma Formation and that the carbon isotope offset present in the core has to be younger than the Carbon Isotope Excursion of the P/E boundary. Either placement is compatible with an Early Eocene age for the 71-21 vertebrate site at Bastrop and the pollen assemblage of the highest Calvert Bluff Formation at Bastrop.

There are some differences in floras of the northwestern and eastern Gulf regions. This is comparable to the dissimilarity of Gulf of Mexico pollen to those of the continental interior of North America, where only two Eocene indicator pollen are common to both areas (Harrington and Jaramillo, 2007). Strong provincialism in floras makes it necessary to generate an independent zonation for each area.

The *Bagelopollis* and *Spineapollis spinosus* zones of Elsik and Crabaugh (2001) have not been used in the eastern Gulf of Mexico region, where the Paleocene-Eocene boundary is placed at or below the top of the Tuscahoma Formation (Harrington and Jaramillo, 2007; Harrington, 2008) based on the Wasatchian NALMA at Red Hot Truck Stop and a report of PETM indicators in the top 3 meters of the Tuscahoma Formation (Sluijs et al., 2014). In the eastern Gulf of Mexico region, *Spineapollis spinosus* and *Bagelopollis* occur within the upper part of the Tuscahoma Formation (Harrington and Jaramillo, 2007).

The reported placement of *Bagelopollis verrucatus* relative to the horizon of the Paleocene/Eocene boundary is not much different in the eastern and northwestern regions of the Gulf of Mexico and may be the same. With the placement of the P/E boundary at a level below the top of the Tuscahoma Formation core at the Red Hot Truck Stop site (Sluijs et al., 2014), the upper Tuscahoma becomes basal Eocene in age. While Sluijs et al. (2014) examined only the upper 3 m of the section, Harrington and Jaramillo (2007) report that the upper 20 m has a similar pollen assemblage, suggesting a P/E boundary placement lower in the section than reported by Sluijs et al. (2014). This opinion is advocated clearly by Fluegeman (2013), based on the ranges of planktic foraminifera in the Tuscahoma Formation. Available data shows that *Bagelopollis verrucatus* is a basal Eocene indicator or appears very close to the P/E boundary.

The status of the *Spineapollis spinosus* zone of Elsik and Crabaugh (2001) is unclear and in doubt. Jardine et al. (2012) reported *Spineapollis spinosus* occurring from the base to the top of the Calvert Bluff Formation. If correct, this places the *Spineapollis spinosus* zone in a horizon normally placed in the late Paleocene, but the range shown for *Spineapollis* by Jardine et al. (2012) is stylized and does not show exact range occurrence in the formation. More data is needed to support this drastic revision in age of the *Spineapollis spinosus* zone. Consequently, the zone will be discounted in this discussion. Evaluation of biostratigraphic zones is a difficult and time-consuming task that requires a large amount of data. A more complete sampling of the Wilcox Group and Carrizo Formation is required to obtain reliable biostratigraphic control in the northwestern Gulf of Mexico.

Difficulties in finding the stratigraphic placement of the Paleocene-Eocene boundary in the Gulf of Mexico coastal plains are based on the need to document the PETM. The P/E boundary is set on the occurrence of the PETM and associated isotopic event and biologic responses to rapid increase in temperatures. In North America, that involves identifying the carbon isotope excursion, migration of biota into the continent from Eurasia, and flood occurrence of *Apectodinium*. Only the short core near the Red Hot Truck Stop in the Gulf Coast region has reasonable evidence of isotopic excursion and *Apectodinium* flood (Sluijs et al., 2014), but the isotopic excursion and flood effects are modest compared to other global sites. Fluegeman (2013) presented a strong argument that the interval reported by Sluijs et al. (2014) is a warming event younger than the PETM and therefore early Eocene but not basal Eocene. This has a strong impact on determination of Paleocene and Eocene palynomorph indicators, illustrated by the uncertainty of the age of the upper Tuscahoma Formation in Mississippi (Harrington and Jaramillo, 2007) that are acknowledged as containing "equivocal Eocene samples" but are considered Paleocene because of occurrence at a level below the Beard and Dawson (2009) and Sluijs et al. (2014) placement of the PETM. Resolution of the placement problem awaits additional data documenting the PETM along with magnetostratigraphy dating of the Wilcox Group section, preferably using core samples.

CARBON ISOTOPES

Carbon isotope values of sediments in the Red Bluff section are similar to values of younger Eocene sediments in Texas (Routh et al., 2001) and contain no evidence of the Paleocene-Eocene carbon isotope event (CIE) or other Early Eocene warming events. Carbon isotopes (Figure 9) vary within a narrow range of -25 to -27 $\delta^{13}C$ with a shift to less negative values at the base of an interval of interbedded mudstone and sandstone that is the transition from Calvert Bluff mudstone to base of the Carrizo Formation. Marine mudstones in the lower 8 meters of section have a narrow range of values between -26 to -27 $\delta^{13}C$ with one interval of more negative values that corresponds in part with samples with minimal organic carbon. This could result from an influx of sediment-rich floodwaters pouring into the shelf environment, diluting the marine plankton and depositing a layer of sediment, but the abundance of algal cysts does not show much increase through this 5 sample zone.

At the 8 m level, carbon isotope values shift to a narrow range of values between -25 to -26 $\delta^{13}C$, with one small excursion in a sample with higher organic carbon. This shift corresponds to a change from dominant mudstone to interbedded mudstone and sandstone as well as low total organic carbon (TOC) values of less than 0.5 % TOC. There is a shift to marine isotope values in sample #101, that contains a 2%+ content of organic carbon (TOC).

Total nitrogen values display trends identical to total organic carbon, tracking the same changes in lithology. Total nitrogen has a narrow range between 0.04 to 0.07% in

lower Calvert Bluff mudstones, apart from a two sample excursion to lower values and a narrow range between 0.02 and 0.04% at the 4 m level and apart from a single sample excursion to 0.07% in a wood-rich sample. The C/N ratio and $\delta^{13}C$ values are important indicators of organic carbon source in sediments (Meyers, 1994). Organic carbon ranges entirely between -25 to -27 $\delta^{13}C$, consistent with a primary source from terrestrial C_3 pathway wood.

All plots, organic carbon isotopes ($\delta^{13}C$) (Figure 9A), total organic carbon (TOC) (Figure 9B), total nitrogen (TON) (Figure 10A), and carbon/nitrogen (C/N) (Figure 10B), have an abrupt shift in values at the level of sample #85 – the base of the interbedded sandstone and mudstone transition where TOC and TON drops to very low values. This is evidence that diagenesis is responsible for changing isotope values and lowering organic carbon and nitrogen content of the sediments resulting from increased fluid flow in the sand layers of the transition interval. The dominant signals in the data set are the stratigraphic trends of upward decrease in organic carbon and nitrogen. These trends are consistent with change in depositional conditions progressing from offshore mud substrate to wave-influenced shorezone with increased sand.

CHAPTER VI

CONCLUSION

The goals of my research were to refine the age of and locate the P/E boundary within these Wilcox sediments and to also verify the depositional setting. Historically, this section was considered to be fluvial in source and entirely within the Paleocene. A more in depth study using palynology and carbon isotopes was needed to refine previous age determinations, as this section was thought to contain the P/E boundary. My study used a very fine scaled sampling method that produced an abundance of palynomorphs, which has shown that these sediments are, in fact, marine in origin and not completely Paleocene in age, although the P/E boundary was not located, either with palynology or carbon isotopic data. The palynomorphs identified here allowed for the identification of basal Eocene indicator taxa, and also allowed for a more detailed environmental assessment of the source areas. A closer look at the section revealed marine influenced sedimentary structures and marine macrofossils, along with the presence of dinoflagellates. This study provides a basis upon which to create a detailed catalog of the provincial flora present in the western Gulf of Mexico during this time.

Although the P/E boundary was not identified within these sediments, it is clear that the boundary is most likely subsurface to the outcropping 71/21 section. Further work using more detailed comparisons to other P/E outcrops and possibly magnetostratigraphy would be beneficial in refining the position of the P/E boundary.

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APPENDIX

		SAMPLE NUMBER										
TAXON	**GROUP**	**2**	**4**	**5**	**8**	**10**	**12**	**15**	**18**	**20**	**21**	**23**
Thompsonipollis magnificus	angio-order unknown	7	5	11	7	6	7	7	11	9	11	2
Spineapollis spinosus	angio-order unknown	3	2	9	1	1	3	0	1	1	1	1
Pistilipollenites	angio-order unknown	0	0	2	0	0	1	2	1	1	1	0
Subtriporopollenites	angio-order unknown	13	11	0	21	23	15	1	0	0	0	4
Tricolpites	angio-order unknown	70	51	44	34	30	59	63	65	58	61	67
Insulapollenites	angio-order unknown	0	0	0	0	0	0	0	3	1	1	0
Quadrapollenites	angio-order unknown	0	0	1	2	2	1	3	0	1	1	0
Inaperturites	angio-order unknown	1	0	0	2	2	0	0	0	0	0	2
Triporopollenites	angio-order unknown	1	0	0	0	0	1	0	0	0	0	1
Liliaceae	monocot	6	2	3	6	3	6	6	2	1	0	9
Favitricolporites	magnoliid	2	2	0	4	5	2	0	6	4	4	3
Sedge	commelinid	0	0	0	0	0	0	0	0	0	0	0
Mauritiidites	commelinid	0	0	0	1	0	0	0	0	0	0	0
Arecaceae	commelinid	8	3	1	7	5	6	4	2	1	1	6
Alnus	rosid	3	0	0	0	0	1	0	0	0	0	1
Ulnus	rosid	1	1	0	0	0	2	3	5	1	1	0
Tricolporites	rosid	8	13	20	17	12	21	9	15	10	7	22
Carya	rosid	2	10	14	4	8	13	8	8	16	15	25
Nudopollis	rosid	0	0	0	2	0	0	0	0	0	0	2
Bagelopollis verrucatus	rosid	0	0	0	0	0	0	0	0	0	0	0
Trudopollis	rosid	0	0	0	0	0	0	0	0	0	0	0
Corylus	rosid	0	0	0	0	0	0	0	0	0	0	0
Castanea	rosid	1	0	0	0	0	0	0	0	0	0	0
Acacia	rosid	0	0	0	0	0	0	0	0	0	0	0
Pterocarya	rosid	0	0	0	0	0	0	0	0	1	1	0
Basopollis	rosid	0	0	0	0	1	0	0	0	0	0	0
Cupuliferopollenites	rosid	14	8	1	7	7	4	0	5	7	6	4

		SAMPLE NUMBER										
TAXON	**GROUP**	**25**	**27**	**30**	**31**	**33**	**35**	**37**	**39**	**40**	**42**	**45**	**46**
T. magnificus	angio-order unknown	12	6	11	9	0	3	5	4	3	3	6	3
S. spinosus	angio-order unknown	3	2	3	2	2	2	2	2	4	1	3	2
Pistilipollenites	angio-order unknown	0	1	0	1	1	3	0	1	3	2	1	1
Subtriporopollenites	angio-order unknown	0	10	0	0	17	0	20	0	0	10	0	11
Tricolpites	angio-order unknown	69	56	62	49	44	80	40	43	41	71	35	38
Insulapollenites	angio-order unknown	0	0	0	0	0	0	0	0	0	0	0	0
Quadrapollenites	angio-order unknown	0	0	0	0	1	1	1	1	0	1	1	1
Inaperturites	angio-order unknown	0	3	1	1	0	1	3	0	0	0	0	0
Triporopollenites	angio-order unknown	0	0	0	0	1	0	2	0	0	0	0	0
Liliaceae	monocot	6	6	4	5	7	1	2	3	7	5	3	4
Favitricolporites	magnoliid	2	7	6	4	1	4	3	3	1	1	8	7
Sedge	commelinid	0	0	0	0	0	0	0	0	0	0	0	0
Mauritiidites	commelinid	1	0	0	0	0	0	0	0	0	0	0	0
Arecaceae	commelinid	2	3	3	2	2	4	3	2	3	5	6	5
Alnus	rosid	0	0	0	0	1	1	0	1	3	0	1	1
Ulnus	rosid	0	0	2	3	1	2	1	0	0	0	0	0
Tricolporites	rosid	14	10	11	16	18	6	11	5	4	28	7	12
Carya	rosid	11	4	23	20	5	18	7	13	18	9	3	4
Nudopollis	rosid	0	0	0	1	1	0	1	2	0	0	1	1
Bagelopollis verrucatus	rosid	0	0	0	0	0	1	0	0	0	0	0	0
Trudopollis	rosid	0	0	0	1	0	0	0	0	0	0	0	0
Corylus	rosid	0	0	0	0	0	0	0	0	0	0	0	0
Castanea	rosid	0	0	0	0	0	0	0	0	0	0	0	0
Acacia	rosid	0	0	0	0	0	0	0	0	1	0	0	0
Pterocarya	rosid	2	0	0	0	0	0	0	1	0	0	3	1
Basopollis	rosid	0	0	1	1	1	0	0	0	0	0	1	1
Cupuliferopollenites	rosid	11	9	10	12	9	3	13	4	2	5	3	4

		SAMPLE NUMBER											
TAXON	**GROUP**	**48**	**50**	**53**	**55**	**58**	**60**	**62**	**64**	**66**	**67**	**69**	**71**
T. magnificus	angio-order unknown	0	2	0	3	6	3	5	3	1	1	0	0
S. spinosus	angio-order unknown	2	1	1	1	2	1	1	2	1	1	2	0
Pistilipollenites	angio-order unknown	1	2	1	1	1	2	1	3	1	1	1	0
Subtriporopollenites	angio-order unknown	17	11	23	13	10	12	17	0	0	0	11	28
Tricolpites	angio-order unknown	44	58	53	50	56	47	38	41	46	50	44	65
Insulapollenites	angio-order unknown	0	0	0	0	0	0	0	0	0	0	0	0
Quadrapollenites	angio-order unknown	1	0	0	0	0	1	0	1	1	1	1	1
Inaperturites	angio-order unknown	0	3	2	2	3	1	2	1	2	2	0	2
Triporopollenites	angio-order unknown	1	0	4	0	0	0	0	0	0	0	1	0
Liliaceae	monocot	7	3	2	3	6	3	1	1	3	4	7	0
Favitricolporites	magnoliid	1	0	2	5	7	4	2	4	2	3	1	2
Sedge	commelinid	0	0	0	0	0	0	0	0	2	2	0	0
Mauritiidites	commelinid	0	0	0	0	0	0	0	0	0	0	0	0
Arecaceae	commelinid	2	6	7	4	3	2	0	4	4	5	2	2
Alnus	rosid	1	1	1	0	0	1	0	1	0	1	1	1
Ulnus	rosid	1	0	0	0	0	0	1	2	0	0	1	1
Tricolporites	rosid	18	9	11	18	24	29	58	39	20	25	19	36
Carya	rosid	5	17	1	5	4	5	6	9	4	2	5	0
Nudopollis	rosid	1	0	0	0	0	0	0	1	0	1	1	0
Bagelopollis verrucatus	rosid	0	0	0	0	0	0	0	0	0	0	0	0
Trudopollis	rosid	1	0	0	0	0	0	0	0	0	0	1	0
Corylus	rosid	0	0	0	0	0	0	0	0	9	3	0	0
Castanea	rosid	0	0	0	0	0	0	0	0	12	4	0	0
Acacia	rosid	0	0	0	0	0	0	0	0	0	0	0	0
Pterocarya	rosid	0	0	0	1	1	1	0	0	0	0	0	0
Basopollis	rosid	1	0	0	0	0	0	0	0	0	0	1	0
Cupuliferopollenites	rosid	9	13	21	14	9	8	11	3	5	7	9	17

		SAMPLE NUMBER										
TAXON	**GROUP**	**2**	**4**	**5**	**8**	**10**	**12**	**15**	**18**	**20**	**21**	**23**
Intratriporopollenites	rosid	1	0	1	2	3	0	2	1	0	1	0
Rhoipites	rosid	12	3	0	1	3	2	0	3	1	2	0
Plicatopollis	rosid	8	6	11	7	8	12	9	11	9	14	6
Quadrapollenites	rosid	0	0	1	2	2	1	3	0	1	1	0
Platycarya	rosid	0	0	6	0	1	1	10	1	0	1	0
Maceopolipollenites	rosid	0	0	0	0	2	0	0	0	0	0	0
Betula/Myrica	rosid	27	17	8	26	20	23	3	13	18	16	14
Lythraceae/*Sonneratia*	rosid	0	0	1	1	1	0	1	0	0	0	0
Casuarina	rosid	10	11	14	17	18	28	10	12	14	15	13
Momipites	rosid	16	22	34	16	19	25	16	53	40	42	41
Rhamnaceae	rosid	1	2	2	4	5	3	2	2	1	1	0
Malvaceae	malvid	0	0	0	0	0	0	0	0	0	0	0
Tilia	malvid	0	1	3	0	2	0	1	0	4	3	4
Bombacaceae	malvid	1	1	4	1	2	1	3	0	1	1	1
Ilexpollenites	campulinid	0	0	0	3	2	0	0	1	0	0	0
Anacolosidites	asterid	0	0	0	0	0	0	0	0	0	0	0
Chenopodium	asterid	0	0	1	0	0	0	0	0	0	0	0
Presymplocoipollenites	asterid	0	0	0	0	0	0	1	3	0	0	0
Symplocoipollenites	asterid	1	0	0	0	0	2	3	0	0	0	0
Nyssa	asterid	11	6	8	6	7	6	0	3	8	7	9
Laevigatosporites	ferns	3	5	7	0	6	7	1	0	6	4	5
Deltoidospora	ferns	1	1	0	0	0	2	0	0	0	0	0
Cyathidites	ferns	0	1	1	0	0	1	0	0	1	0	0
Lycopodium	ferns	1	0	0	0	0	0	0	0	0	0	0
Ciciatricosisporites	ferns	4	3	4	4	6	0	0	1	3	2	8
Trilete spores undiff	ferns	0	2	10	0	0	0	4	0	3	3	5

		SAMPLE NUMBER											
TAXON	**GROUP**	**25**	**27**	**30**	**31**	**33**	**35**	**37**	**39**	**40**	**42**	**45**	**46**
Intratriporopollenites	rosid	3	3	1	1	0	0	2	0	0	0	0	0
Rhoipites	rosid	3	0	0	7	0	4	0	0	0		0	1
Plicatopollis	rosid	11	11	7	10	7	2	12	5	3	4	4	6
Quadrapollenites	rosid	0	0	0	1	1	1	1	0	0		1	1
Platycarya	rosid	2	0	0	0	0	0	0	0	1	0	0	0
Maceopolipollenites	rosid	0	0	0	0	1	0	1	0	0	0	0	0
Betula/Myrica	rosid	14	16	16	17	12	12	11	10	8	18	10	13
Lythraceae/*Sonneratia*	rosid	1	0	0	0	0	0	0	0	0	1	0	0
Casuarina	rosid	12	9	9	11	21	9	7	11	8	9	21	24
Momipites	rosid	33	36	41	37	41	42	28	31	29	47	39	42
Rhamnaceae	rosid	3	0	3	4	3	0	6	3	2	2	1	1
Malvaceae	malvid	0	0	0	0	1	0	0	0	0	0	0	0
Tilia	malvid	0	0	0	0	0	0	0	0	0	0	0	0
Bombacaceae	malvid	0	0	5	4	2	3	0	2	3	0	5	4
Ilexpollenites	campulinid	0	0	0	0	1	0	0	0	0	0	0	0
Anacolosidites	asterid	0	0	0	0	0	0	0	0	0	0	0	0
Chenopodium	asterid	0	0	1	1	0	0	1	0	0	1	0	0
Presymplocoipollenites	asterid	2	0	0	0	0	2	0	0	0	0	0	0
Symplocoipollenites	asterid	0	0	0	3	0	0	0	0	0	0	1	1
Nyssa	asterid	5	8	13	15	3	25	9	18	15	12	22	18
Laevigatosporites	ferns	8	1	3	4	6	11	5	6	6	1	4	3
Deltoidospora	ferns	0	0	0	0	3	0	0	0	0	2	0	0
Cyathidites	ferns	0	0	2	1	0	1	1	0	0	2	0	0
Lycopodium	ferns	0	0	0	0	0	0	1	1	0	0	0	0
Ciciatricosisporites	ferns	1	0	0	1	1	3	6	6	0	0	0	1
Trilete spores undiff	ferns	0	1	1	0	3	0	4	6	0	0	2	2

		SAMPLE NUMBER											
TAXON	**GROUP**	**48**	**50**	**53**	**55**	**58**	**60**	**62**	**64**	**66**	**67**	**69**	**71**
Intratriporopollenites	rosid	0	0	0	3	3	1	0	0	0	0	0	1
Rhoipites	rosid	7	5	7	4	3	3	4	0	2	4	7	1
Plicatopollis	rosid	7	4	8	7	11	9	3	2	8	9	7	1
Quadrapollenites	rosid	1	0	0	0	0	1	0	1	1	1	1	1
Platycarya	rosid	0	0	0	0	0	0	0	0	0	0	0	0
Maceopolipollenites	rosid	1	0	1	0	0	0	0	0	1	0	1	0
Betula/Myrica	rosid	12	15	2	15	17	19	14	12	11	9	12	12
Lythraceae/*Sonneratia*	rosid	0	0	0	0	0	0	1	0	4	3	0	0
Casuarina	rosid	21	23	4	6	9	8	6	9	6	5	11	2
Momipites	rosid	41	35	28	29	23	25	21	24	31	26	24	15
Rhamnaceae	rosid	3	0	4	1	1	1	2	0	3	2	3	6
Malvaceae	malvid	1	0	1	0	0	0	0	0	0	0	1	0
Tilia	malvid	0	0	0	0	0	0	0	0	0	0	0	0
Bombacaceae	malvid	2	0	2	0	0	0	4	3	3	4	2	2
Ilexpollenites	campulinid	1	0	0	0	0	0	0	0	2	2	1	0
Anacolosidites	asterid	0	0	0	0	0	0	1	0	0	0	0	0
Chenopodium	asterid	0	0	0	0	0	0	0	0	1	1	0	1
Presymplocoipollenites	asterid	0	0	0	0	0	0	0	0	1	1	0	0
Symplocoipollenites	asterid	3	2	2	0	0	0	0	0	1	1	3	1
Nyssa	asterid	3	17	25	11	8	11	17	20	14	11	7	8
Laevigatosporites	ferns	6	3	1	4	5	6	0	11	2	7	6	1
Deltoidospora	ferns	3	0	1	0	0	0	0	0	0	0	3	0
Cyathidites	ferns	0	0	0	0	0	0	1	1	2	1	0	0
Lycopodium	ferns	0	0	0	0	0	0	0	0	0	0	0	0
Ciciatricosisporites	ferns	1	1	1	1	1	0	1	1	2	1	1	0
Trilete spores undiff	ferns	0	1	0	2	2	2	0	3	0	1	0	0

		SAMPLE NUMBER										
TAXON	**GROUP**	**2**	**4**	**5**	**8**	**10**	**12**	**15**	**18**	**20**	**21**	**23**
Bisaccate undiff	gymnosperm	0	0	0	2	2	0	0	0	0	0	0
Abies	gymnosperm	0	0	0	0	0	0	0	0	0	0	0
Ephedra	gymnosperm	0	0	0	3	0	0	0	0	0	0	0
Taxodium	gymnosperm	4	6	9	7	9	2	23	4	8	6	2
Corollina	gymnosperm	0	1	5	0	0	1	1	0	0	0	0
Cycadales	gymnosperm	0	0	1	2	1	0	0	1	2	1	1
Sphagnum	non-vascular	1	0	3	0	1	1	1	1	2	0	2
Fungal undiff	fungal	8	9	12	12	8	4	11	5	8	7	3
Didymoporisporinites sp.	fungal	0	0	0	0	0	0	0	0	0	0	0
Exesisporites sp.	fungal	6	0	0	0	0	0	0	0	0	0	0
Dyadosporites sp.	fungal	0	0	0	0	0	0	0	0	0	0	1
Portalites sp.	fungal	1	0	0	0	0	0	0	0	0	0	0
Fusiformisporites sp.	fungal	0	0	0	0	0	0	0	0	0	0	0
Pluricellaesporites sp.	fungal	0	0	0	0	0	0	0	0	0	0	0
Diporopollis	fungal	0	0	0	0	0	0	0	0	0	0	2
Foveodiporites	fungal	0	0	0	1	0	0	0	0	0	0	0
Diporicellaesporites	fungal	0	0	0	0	0	0	0	0	0	0	0
Diporisporites hamenii	fungal	0	0	0	0	0	0	0	0	0	0	0
Brachysisporites	fungal	0	0	0	0	0	0	0	0	0	0	0
Schizaceae	fw algal	2	2	1	1	2	7	5	1	1	1	1
Algal undiff	algal	20	19	16	19	17	13	47	4	7	8	13
Botryoccus	algal	0	0	0	0	0	0	0	0	0	0	1
Tetraporina	fw algal	0	0	0	0	0	0	0	0	0	0	0
A. homomorphum	dinoflagellate	0	0	0	0	0	0	0	0	0	0	1
Cordosphaeridium	dinoflagellate	0	0	0	0	0	0	0	0	0	0	0

		SAMPLE NUMBER										
TAXON	**GROUP**	**25**	**27**	**30**	**31**	**33**	**35**	**37**	**39**	**40**	**42**	**45**	**46**
Bisaccate undiff	gymnosperm	0	1	0	0	1	1	1	1	0	0	3	2
Abies	gymnosperm	0	0	0	0	0	0	0	0	0	1	0	0
Ephedra	gymnosperm	0	1	0	0	0	0	0	1	1	0	0	0
Taxodium	gymnosperm	8	8	4	5	6	5	11	4	2	0	2	5
Corollina	gymnosperm	0	0	1	1	2	2	1	0	0	0	0	0
Cycadales	gymnosperm	0	2	1	2	6	1	2	2	0	0	1	1
Sphagnum	non-vascular	1	2	2	1	4	1	0	0	1	0	1	2
Fungal undiff	fungal	12	7	18	13	11	4	8	13	12	10	2	4
Didymoporisporinites sp.	fungal	0	0	0	0	0	0	0	0	0	0	0	0
Exesisporites sp.	fungal	0	0	0	0	0	0	0	0	0	0	0	0
Dyadosporites sp.	fungal	0	0	0	0	0	0	0	0	0	0	0	0
Portalites sp.	fungal	0	0	0	0	0	0	0	0	0	0	0	0
Fusiformisporites sp.	fungal	0	0	0	0	0	0	0	0	0	0	0	0
Pluricellaesporites sp.	fungal	0	0	0	0	0	0	0	0	0	0	0	0
Diporopollis	fungal	0	0	0	0	0	0	0	0	0	0	0	0
Foveodiporites	fungal	0	0	0	0	0	0	0	0	0	0	0	0
Diporicellaesporites	fungal	0	0	0	0	0	0	0	0	0	0	0	0
Diporisporites hamenii	fungal	0	0	0	0	0	0	0	0	0	0	0	0
Brachysisporites	fungal	0	0	0	0	0	0	0	0	0	0	0	0
Schizaceae	fw algal	5	0	1	2	3	0	0	2	2	7	1	3
Algal undiff	algal	6	10	6	8	10	4	5	8	9	14	4	6
Botryoccus	algal	0	0	0	0	0	0	0	0	0	0	0	0
Tetraporina	fw algal	0	0	0	0	0	0	0	0	0	0	0	0
A. homomorphum	dinoflagellate	0	0	0	0	1	0	0	0	0	0	0	0
Cordosphaeridium	dinoflagellate	0	0	0	0	0	0	0	0	0	0	0	0

		SAMPLE NUMBER											
TAXON	**GROUP**	**48**	**50**	**53**	**55**	**58**	**60**	**62**	**64**	**66**	**67**	**69**	**71**
Bisaccate undiff	gymnosperm	1	0	0	1	1	1	1	1	2	1	1	0
Abies	gymnosperm	0	0	0	0	0	0	0	0	0	0	0	0
Ephedra	gymnosperm	0	0	0	0	1	0	0	0	0	0	0	0
Taxodium	gymnosperm	6	2	1	9	8	7	4	5	11	8	6	12
Corollina	gymnosperm	1	0	1	0	0	0	0	2	1	2	1	3
Cycadales	gymnosperm	2	1	0	0	0	0	0	6	2	2	2	0
Sphagnum	non-vascular	4	1	0	2	2	1	2	1	3	2	4	4
Fungal undiff	fungal	11	7	0	7	7	9	8	8	25	19	15	12
Didymoporisporinites sp.	fungal	0	0	0	0	0	0	0	0	0	0	0	0
Exesisporites sp.	fungal	0	0	0	0	0	0	1	0	0	0	0	0
Dyadosporites sp.	fungal	0	0	0	0	0	0	1	1	0	0	0	0
Portalites sp.	fungal	0	0	0	0	0	0	0	0	0	0	0	0
Fusiformisporites sp.	fungal	0	0	0	0	0	0	0	0	0	0	0	0
Pluricellaesporites sp.	fungal	0	0	0	0	0	0	0	0	0	0	1	0
Diporopollis	fungal	0	0	0	0	0	0	0	0	0	0	0	1
Foveodiporites	fungal	0	0	0	0	0	0	0	0	0	0	0	0
Diporicellaesporites	fungal	0	0	0	0	1	0	0	0	0	0	0	0
Diporisporites hamenii	fungal	0	0	0	0	0	0	0	0	0	0	0	0
Brachysisporites	fungal	0	0	0	0	0	0	0	0	0	0	0	1
Schizaceae	fw algal	3	1	4	2	2	1	5	0	0	1	3	2
Algal undiff	algal	10	20	26	27	32	27	9	3	27	23	17	26
Botryoccus	algal	0	0	0	0	0	0	0	0	0	0	0	0
Tetraporina	fw algal	0	0	0	0	0	0	0	0	0	0	0	2
A. homomorphum	dinoflagellate	0	0	0	0	0	0	1	0	0	0	0	0
Cordosphaeridium	dinoflagellate	0	0	0	0	0	0	0	0	0	0	0	1